Linking Capacity Expansion, Resource Adequacy, and Production Cost Modeling Tools for Integrated Strategic System Planning

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Acknowledgments

EPRI prepared this report.

Principal Investigators
P. de Mello
N. Goteti
M. Ortega-Vazquez
N. Santen

Contributors
G. de Mijolla
Q. Zhu

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Finally, we would like to extend our appreciation to the industry members of the ISSP Strategic Planning Executive Advisory Group and industry participants of the Linking Capacity Expansion and Production Cost Modeling Tools Technical Working Groups for their questions and guidance throughout the research process.

This publication is a corporate document that should be cited in the literature in the following manner:
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Abstract

EPRI’s Integrated Strategic System Planning (ISSP) Initiative developed a new framework and analytical toolbox for more comprehensively planning across generation, transmission, distribution, and end-use systems, and realizing cost-effective and reliable low-carbon electric power systems. The overall framework consists of a series of soft-linked power system modeling tools, including (1) an economic energy-systems planning model to develop regional technology pathways; (2) a detailed, nodal generation and transmission capacity expansion planning model to develop system-level resource expansion portfolios; (3) a series of grid operations simulation models to evaluate resource adequacy and system risk; and (4) distribution planning tools to assess potential distribution network upgrades and non-wires alternatives.

The research presented in this report focuses on the modeling linking efforts between tools identified in (1), (2), and a portion of (3) above. The motivation for this work is that cost-effective, low-carbon electricity transition planning requires analytical tools and processes that consider key policy, technology, and market impacts across broad, interconnected power systems; as well as critical grid operations and reliability needs given higher levels of variable renewable energy, distributed energy resources, and storage assets. And simply, existing long-term planning modeling tools do not adequately meet both requirements.

Focusing on the bulk power system, this research leverages and links a zonal economic energy-systems planning model, a nodal unit-level capacity expansion planning model, and resource adequacy and production cost models for planning low-carbon and high-renewable long-term resource portfolios that are robust to potential future reliability and resource adequacy deficiencies.

Keywords

Integrated system planning; resource portfolio planning; electric power system modeling; decarbonization planning; power system reliability

Executive Summary

Deliverable Number: 3002028534
Product Type: Technical Update
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Primary Audience: Electric company staff engaged in long-term generation portfolio resource planning, transmission planning, integrated resource planning, decarbonization planning, and/or corporate strategy and risk management.

Secondary Audience: Regulators, policy makers, ISO/RTO staff, reliability organization staff, and others who are interested in integrated system planning strategy and novel modeling approaches for decarbonization planning.

RESEARCH OVERVIEW

Cost-effective, low-carbon electricity transition planning requires analytical tools and processes that consider key policy, technology, and market impacts across broad, interconnected power systems; as well as critical grid operations and reliability needs given higher levels of variable renewable energy, distributed energy resources, and storage assets. Existing long-term planning modeling tools do not adequately meet these requirements. Focusing on the bulk power system, this research leverages and links a zonal economic energy-systems technology pathways model, a nodal unit-level capacity expansion planning model, and resource adequacy and production cost models for planning low-carbon and high-renewable long-term resource portfolios that are robust to potential future reliability and resource adequacy deficiencies.

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KEY FINDINGS

- **Linking Zonal Technology Pathways Models & Nodal Capacity Expansion Planning Models**
  - Regional technology planning models provide a critical starting point for detailed unit-level capacity expansion and operations-level analyses.
  - There are multiple tradeoffs between spatial vs. temporal granularity in datasets when moving from a zonal technology-level model to a nodal unit-based model.
  - Linking zonal technology planning & nodal CEP models requires large volumes of data management & transfer.
  - The overall framework is tool agnostic, but differences in model structure, operating systems, and data management software make implementation of the framework heavily tool dependent.

- **Improving Capacity Expansion Portfolios with Resource Adequacy and Operational Reliability Evaluations**
  - Traditional PCM and RA modeling remain valuable to system planning.
  - Data management and validation continues to be a challenge across model types, even with a common software platform.
  - Scoping each simulation can help save time and effort; this can include time horizon, time step, and geography needs.
  - Balance between simulation detail, run time, and post processing effort is essential; more detailed simulations aren't better if the underlying data is not accurate.

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KEY FINDINGS (continued)

- **Using Risk Analysis to Develop Robust Capacity Expansion Portfolios**
  - Operating risk is an important system specific metric to evaluate because it captures the dynamic nature of operating conditions (e.g., scheduling, dispatch, VRES, demand, and reliability of assets) and can be mitigated by smart and strategic scheduling of operating reserves.
  - Evaluating operating risk and mitigation strategies allows sending a feedback signal to capacity expansion planning tools to invest in more efficient and reliability enhancing resources.
  - Energy storage technologies can be a double-edged sword. They can allow for efficient system operations and reduce stress during peaks but may also mask the need for other reserve providing resources, which can increase risk.

- **WHY THIS MATTERS**
  The ISSP Initiative developed a first-of-a-kind, generalizable framework and analytical toolbox for integrated strategic planning across generation, transmission, distribution, and end-use systems, and for realizing cost-effective and reliable low-carbon electric power systems. The framework is tool agnostic, allowing individuals and organizations interested in adopting EPRI’s ISSP approach to do so with many of the analytical tools they already use.

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HOW TO APPLY RESULTS

The ISSP modeling framework is generalizable and is intended to be applied using a range of power system modeling tools already in use by electric companies and other industry stakeholders. Individuals or organizations interested in applying the ISSP framework or portions of it are encouraged to speak with their software vendors to assess their models' capabilities to support the links presented in this study, or follow-up with the EPRI contact below for a customized model road-mapping assessment.

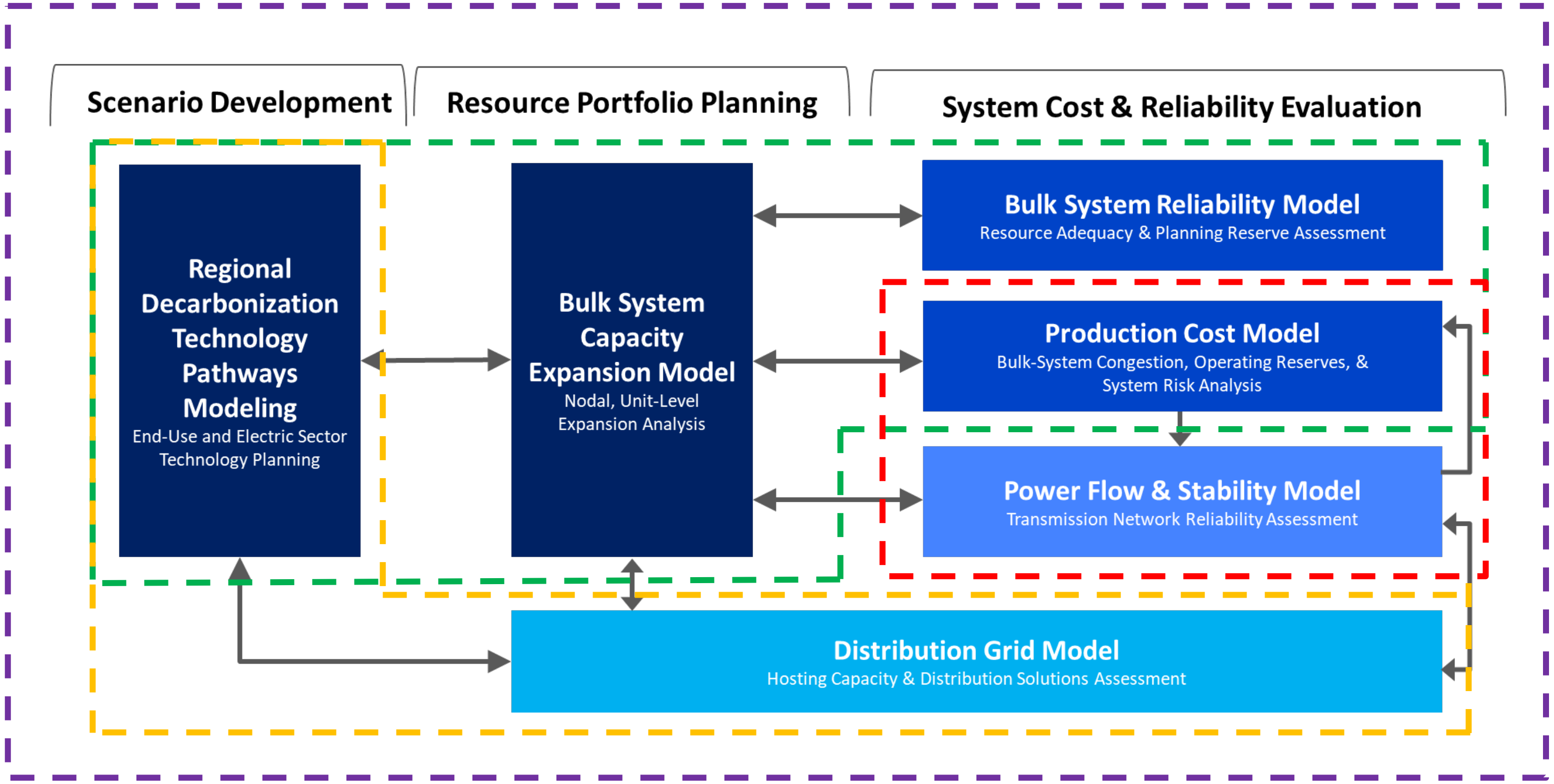
LEARNING AND ENGAGEMENT OPPORTUNITIES

- Implementing Integrated System Planning (ISP) Interest Group. EPRI Contact: Nidhi Santen, nsanten@epri.com
- Climate READi (REsilience and ADaptation initiative). https://www.epri.com/research/sectors/readi. EPRI Contact: Morgan Scott, mmscot@epri.com

EPRI CONTACTS: Nidhi Santen, Program Manager (nsanten@epri.com); Phillip de Mello, Sr. Technical Leader (pdemello@epri.com); Miguel Ortega-Vazquez, Sr. Principal Team Lead (mortegavazquez@epri.com)

PROGRAMS: Bulk System Integration of Renewables and Distributed Energy Resources (P173), Resource Planning for Electric Power Systems (P178), Energy, Environmental, and Climate Policy Analysis (P201); Electricity Market Design and Operation (P246)

EPRI Integrated Strategic System Planning (ISSP) Initiative Technical Report Series



Scenario Development

Resource Portfolio Planning

System Cost & Reliability Evaluation

Regional Decarbonization Technology Pathways Modeling
End-Use and Electric Sector Technology Planning

Bulk System Capacity Expansion Model
Nodal, Unit-Level Expansion Analysis

Bulk System Reliability Model
Resource Adequacy & Planning Reserve Assessment

Production Cost Model
Bulk-System Congestion, Operating Reserves, & System Risk Analysis

Power Flow & Stability Model
Transmission Network Reliability Assessment

Distribution Grid Model
Hosting Capacity & Distribution Solutions Assessment

Integrated Strategic System Planning Initiative: Modeling Framework, Demonstration Study Results, and Key Insights
(Product ID 3002028640)

Linking Capacity Expansion, Resource Adequacy, and Production Cost Modeling Tools for Integrated Strategic System Planning
(Product ID 3002028534)

Guidelines for Linking Power Flow Analysis with Production Cost Modeling Tools for Integrated Strategic System Planning: Needs, Screening Methods, and Best Practices
(Product ID 3002028535)

Wide-Area Distribution Assessments for Integrated Strategic System Planning
(Product ID 3002028536)

Other Reports:

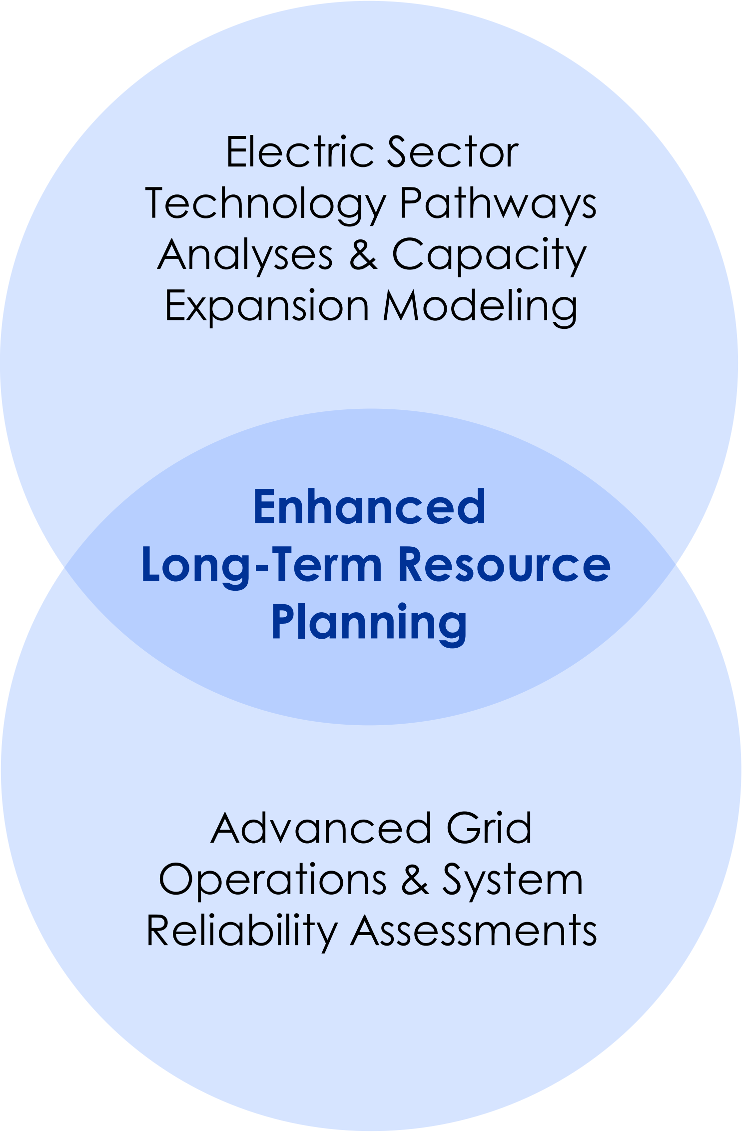
- Current Modeling Capabilities and Practices for Integrated Planning: Review of Select Modeling Tools and Prominent Studies (Product ID 3002028537)
- A Distribution Perspective of Process, Capabilities, and Data for Integrated Planning (Product ID 3002028538)

Table of Contents

Overview of Research Framework & Demonstration Study

Introduction

- Cost-effective, low-carbon electricity transition planning requires analytical tools and processes that consider
  - key policy, technology, and market impacts across broad, interconnected power systems, and
  - critical grid operations and reliability needs from higher variable renewable energy and distributed energy resource levels, and new system configurations (e.g., storage assets)
- Existing planning frameworks may be inadequate to meet both dimensions
- **This research develops a framework and modeling toolset for planning low-carbon and high-renewable resource portfolios robust to potential future reliability and resource adequacy deficiencies.**
- The research described in this report provided the tools and links highlighted in green in EPRI's Integrated Strategic System Planning Initiative's Toolbox (shown on the next slide).



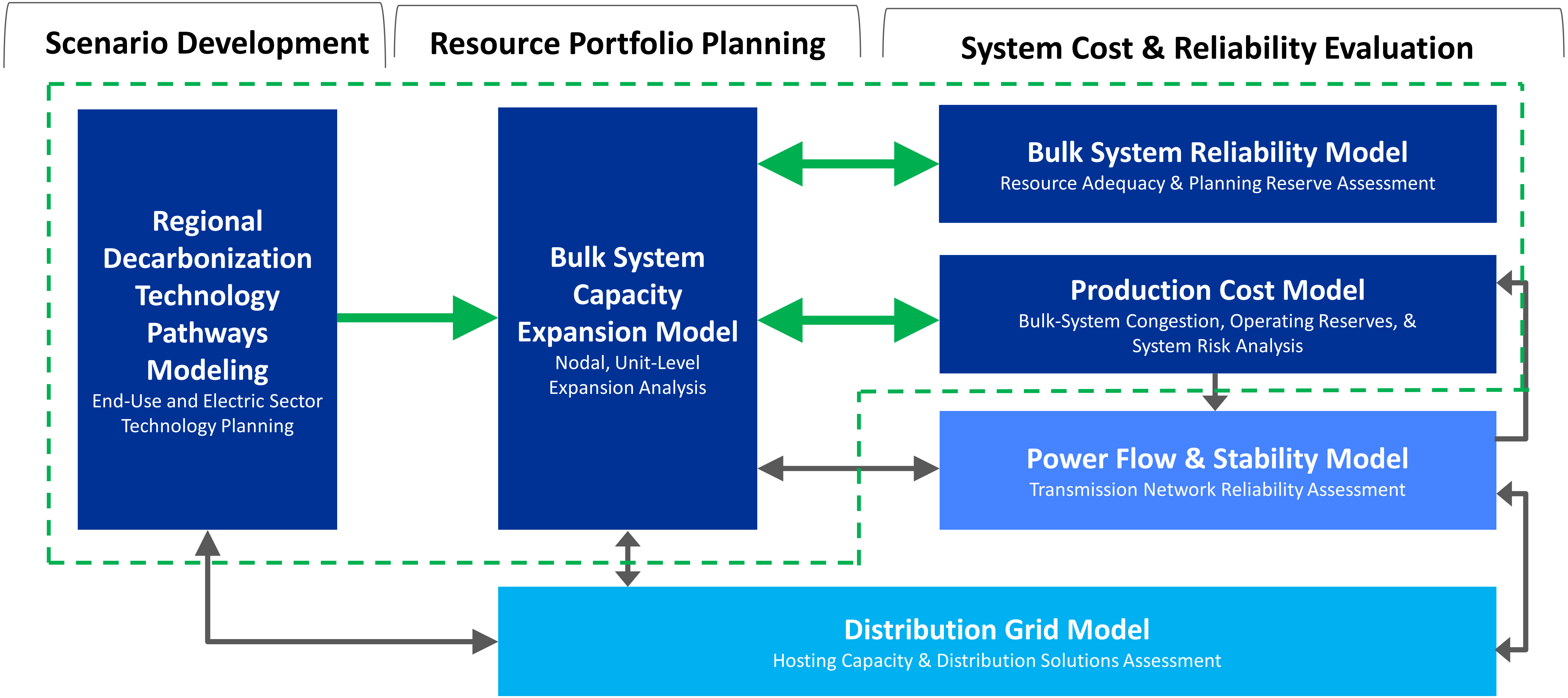
Electric Sector Technology Pathways Analyses & Capacity Expansion Modeling

Enhanced Long-Term Resource Planning

Advanced Grid Operations & System Reliability Assessments

EPRI's Integrated Strategic System Planning (ISSP) Analytical Framework & Modeling Toolbox

Research described in this report developed the emphasized links shown in green



Scenario Development

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Distribution Grid Model
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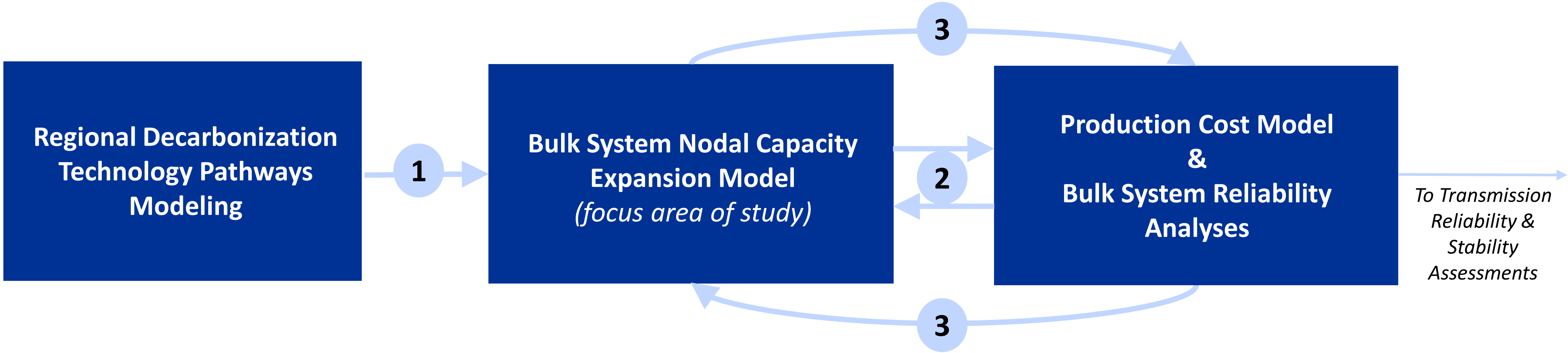
Summary of Approach: Linking Capacity Expansion & Grid Operations Models to Identify Robust Portfolios



1 **Portfolio Translation by Soft-Linking Models**

Analyze technology pathways and **extract assumptions and results** to inform detailed unit-level expansion planning model of candidate resources

2

Grid Simulations

Evaluate initial G&T buildouts by identifying system performance characteristics through **resource adequacy** and **hourly and sub-hourly production cost modeling**

Initial Screening & Adjustments

Screen capacity expansion buildouts and **adjust common planning levers** in the capacity expansion planning model

3

Data Analysis

Parse data to **identify representative and critical operating periods**. Analyze periods to **check reliability under multiple realizations of adverse conditions**

Risk Analysis & Adjustments

Assess system risk exposure to continuous (i.e., variability and uncertainty) and discrete (i.e., contingencies) events; triggers additional analysis or **new approximated reliability constraints**

New York System Demonstration Study

Framing Question 1

Which technologies support meeting a decarbonized electricity sector in NY by 2035?

How does this compare to business as usual?

Framing Question 2

How reliable is that future decarbonized NY power system?

Framing Question 3

How may NY generation portfolios be modified to cost-effectively respond to potential reliability scarcity or excesses?

Can robust portfolios be identified?

A defined system of study (NY) and a stylized set of framing questions facilitated developing the needed links between tools to perform more integrated planning studies.

NY Demonstration Study Scenarios

Assumptions	Reference	Decarbonization + Accelerated Electrification
	"Business-as-usual" with no additional decarbonization technology or policy drivers	Rapid U.S.-wide decarbonization, driven by policy and high electrification

Environmental and CO_2 Policies	All major "on the books" federal, regional, and state environmental and climate policies
	• Includes New York's SB6599 (CLCPA)
		Reference, plus
		• U.S. electric sector is zero carbon by 2035
		  • No negative emissions or offsets permitted
		  • Interim 80% carbon-free by 2030 target
		• U.S.-wide carbon pricing over the rest of the economy, consistent with a U.S. 50x2030 goal

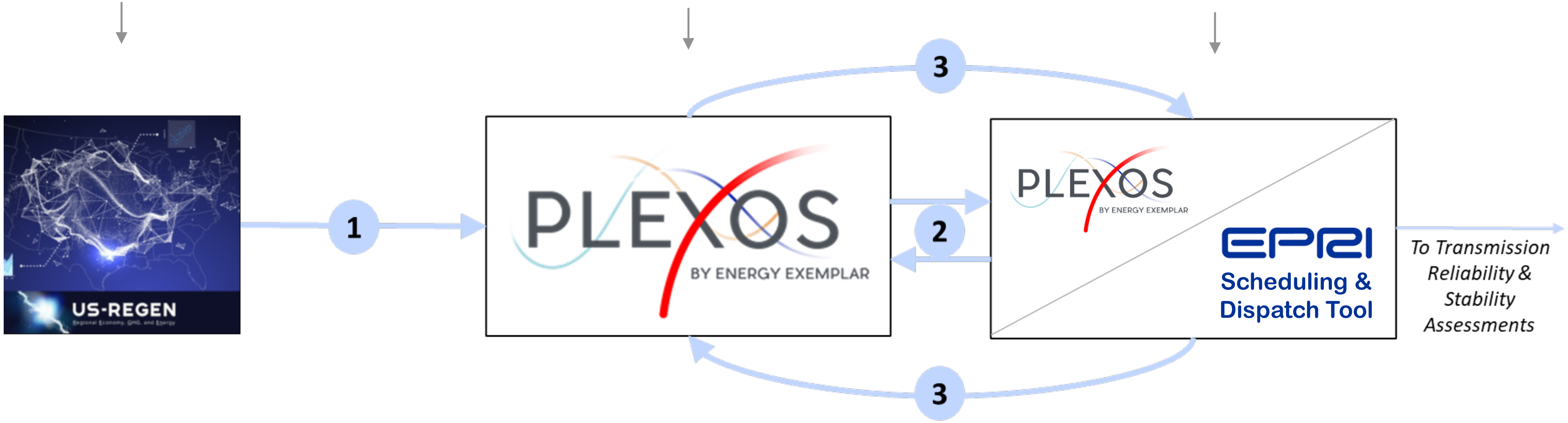
Technology	Default EPRI inputs for technology cost and performance	Reference, plus • Faster diffusion of electrified consumer technologies: • Accelerated heat pump adoption • Accelerated turnover of existing end-use equipment • Lower cost and higher performance electric vehicles and heat pumps

NY Demonstration Study Toolbox

Regional
Decarbonization
Technology Pathways
Model

Nodal
Unit-Level
Capacity Expansion
Planning Model

Production Cost Model
&
System Reliability
Analyses

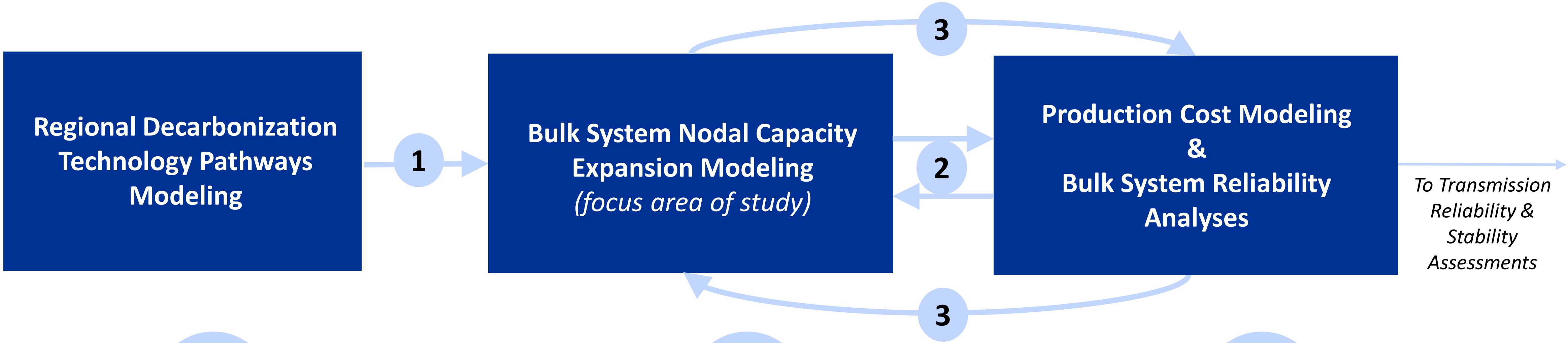


Scheduling & Dispatch Tool

To Transmission Reliability & Stability Assessments

EPRI's ISSP Initiative develops a tool "agnostic" framework, demonstrated in this research using EPRI's US-REGEN model, Energy Exemplar's PLEXOS models, and an EPRI-developed in-house scheduling and dispatch tool.

Report Roadmap



1

This section details Link "1" in the diagram above. It describes scenario development for the NY demonstration study using EPRI's US-REGEN model, and why and how scenario results are used to inform more geographically granular capacity expansion planning (CEP) for NYISO.

2

This section details the links labeled "2" in the diagram above.

It describes a series of initial resource adequacy and production cost-modeling based grid operations reliability screening checks, and opportunities to improve the NYISO CEP model via feedback.

3

This section details the links labeled "3" in the diagram above.

It describes a second series of PCM-based grid operational reliability checks—using a detailed risk analysis—on the capacity expansion portfolio under evaluation, and additional opportunities to improve the NYISO CEP model.

1

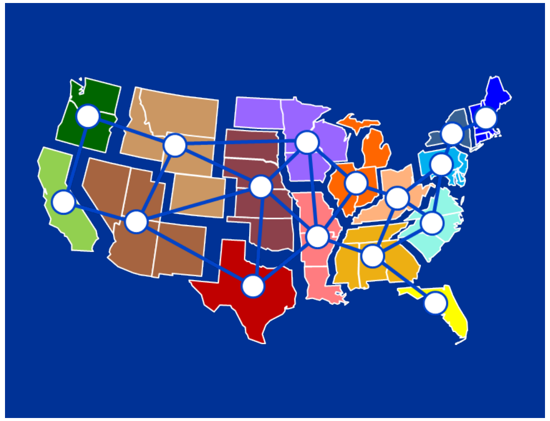
“Soft-Linking” Technology Pathway Models & Nodal, Unit-Level Capacity Expansion Models

1

"Soft-Linking" Technology-Level Energy System Planning & Unit-Level Capacity Expansion Planning

Objective

- To inform unit-level capacity expansion planning (CEP) models with capacity portfolio results from national/regional CEP analyses
  - Impacts of multi-state markets and national environmental credit trading opportunities
  - Impacts from broader interactions between high-renewable connected systems.
- Provide unit-level CEP model with an informed "starting point" of candidate generation technologies to optimize the system for deep decarbonization futures
  - Manage computational feasibility by providing granular unit-level models with a discrete number of informed choices
- Align key inputs, outputs, and assumptions between linked models to support analysis using a consistent framework

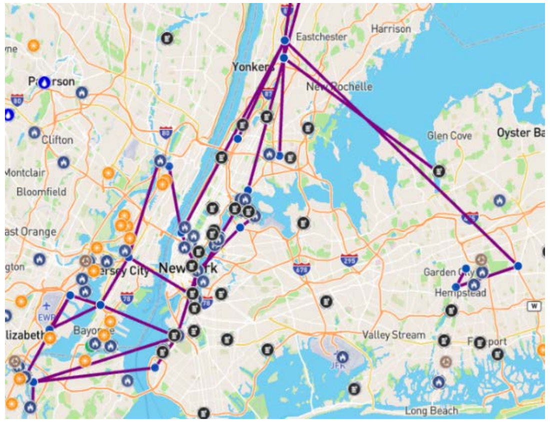


US-REGEN*

NY—1 zone (1 node)
Technology capacity "blocks"
16 US regions
"Pipe & bubble" transmission network

*US-REGEN is spatially customizable

↓



PLEXOS

NY—11 zones
(5202 nodes)
Individual EGUs
Nodal transmission network
DC Optimal Power Flow

(Snapshot is NYC)

Technology Pathway Modeling Objectives

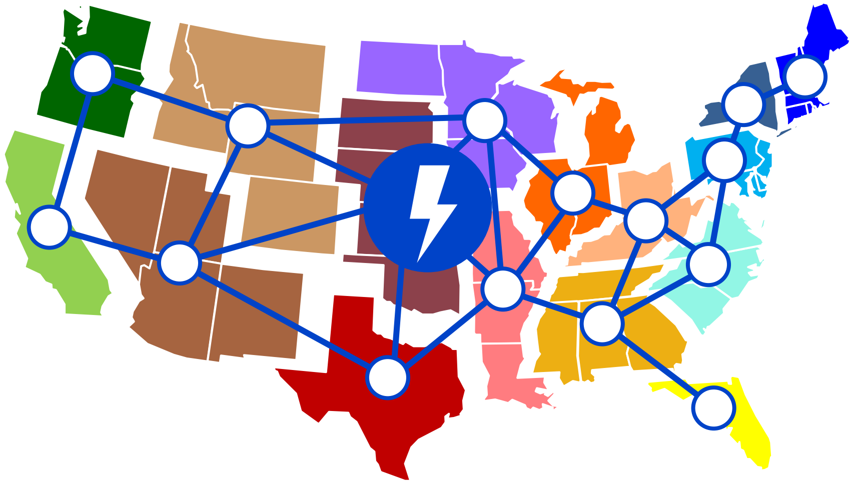
- Optimal decarbonization portfolios should consider potential impacts of multi-state markets, environmental credit trading, neighboring high-renewable systems, electrification, and more.
- Assessing a broad range of low and zero-carbon technology solutions and their market potentials is also beneficial for efficient planning
  - More granular capacity expansion planning models are not designed to feasibly solve over the full range of possible new resource investment choices (due to dimensionality burdens)
- EPRI’s US-REGEN model provides electricity loads and optimal technology portfolios in technology “blocks” (GW) for each region, subject to interactions and constraints between all regions modeled

US-REGEN

Regional Economy, GHG, and Energy

Regional Decarbonization Technology Pathways Modeling

Electric Generation



Detailed representation of:

- Energy and capacity requirements
- Renewable integration, transmission, storage
- Federal, regional, and state-level policies and constraints

Synchronized

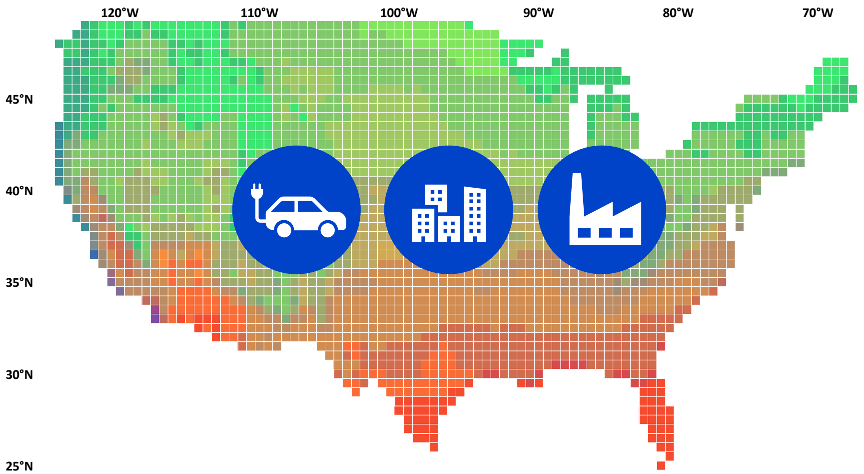
Hourly Load, Renewables, and Prices

Model Outputs:

Economic equilibrium for generation, capacity, and end-use mix

Emissions, air quality, and water

Energy Use

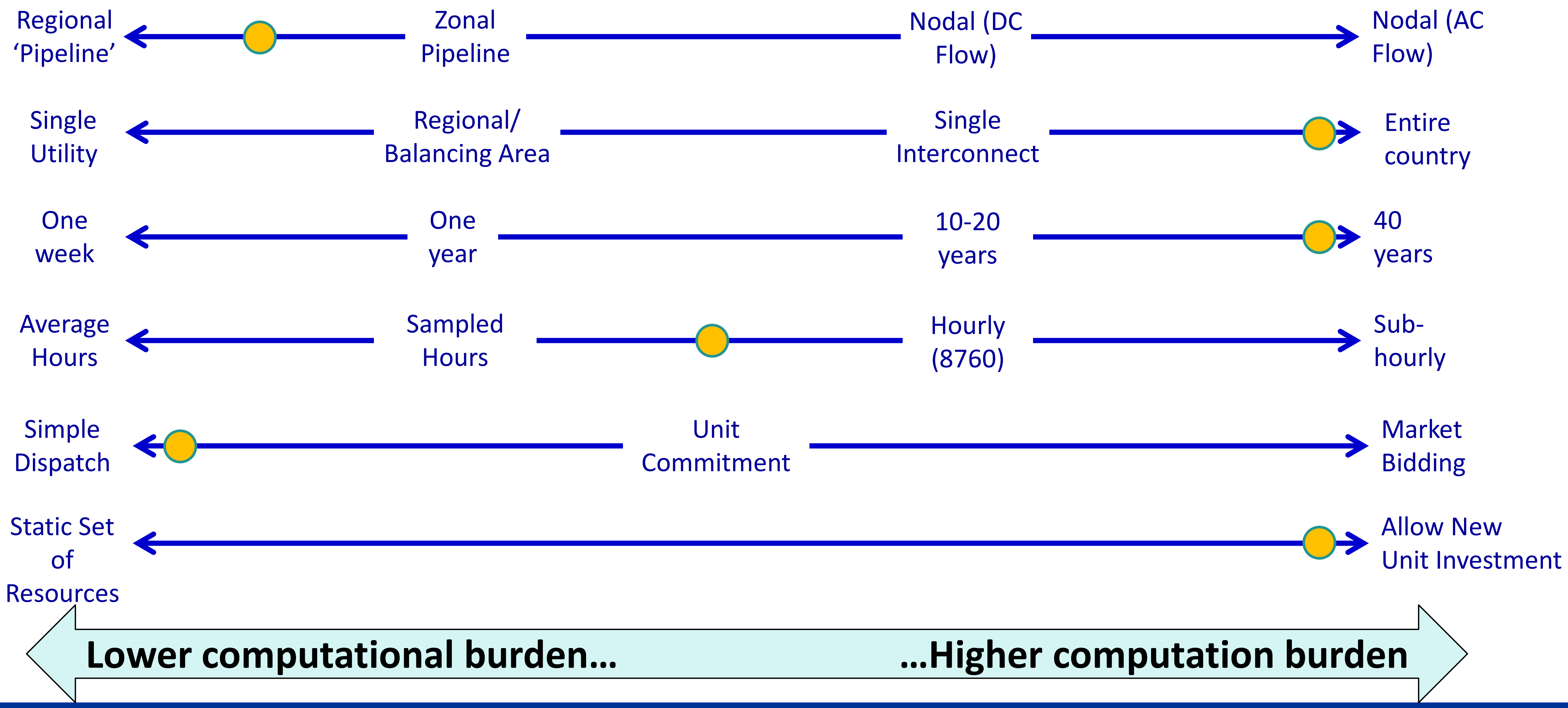


Detailed representation of:

- Customer heterogeneity across end-use sectors
- End-use technology trade-offs
- Electrification and efficiency opportunities

Documentation, articles, and reports available at https://esca.epri.com

REGEN: Dynamic Capacity Expansion Model



Regional 'Pipeline' – Zonal Pipeline – Nodal (DC Flow) – Nodal (AC Flow)

Single Utility – Regional/ Balancing Area – Single Interconnect – Entire country

One week – One year – 10-20 years – 40 years

Average Hours – Sampled Hours – Hourly (8760) – Sub-hourly

Simple Dispatch – Unit Commitment – Market Bidding

Static Set of Resources – Allow New Unit Investment

Lower computational burden… …Higher computation burden

REGEN design choices optimized to explore long-run system change

Renewables and Storage Technologies in REGEN

Variable Renewable Technologies

🟨	Solar PV	Many configurations (e.g., fixed tilt, single-axis tracking, dual-axis tracking); resources classes by state
🟫	Solar CSP	Endogenous selection of thermal storage
▨	Solar Rooftop	Adoption captured in end-use model, and profile is exogenous input to electric sector model
🟩	Onshore Wind	Technology and output profile vary by resource class, state, and vintage (e.g., 120-m hub height in 2030)
🟩	Offshore Wind	Fixed platform with technology variation by resource class, state, and vintage (e.g., 140-m hub height in 2035)

Energy Storage Technologies

🟪	Battery	Cost structure as input ($/kW power capacity, $/kWh energy capacity); duration and total deployment as outputs
🟧	Compressed Air	Natural gas as factor input
🟥	H_2/Electrolysis	Capacity of production via electrolysis, H_2 storage, and generation from turbines all optimized independently
🟦	Pumped Hydro	Existing capacity endowment, no expansion

Dispatchable/Firm/On-Demand Renewables

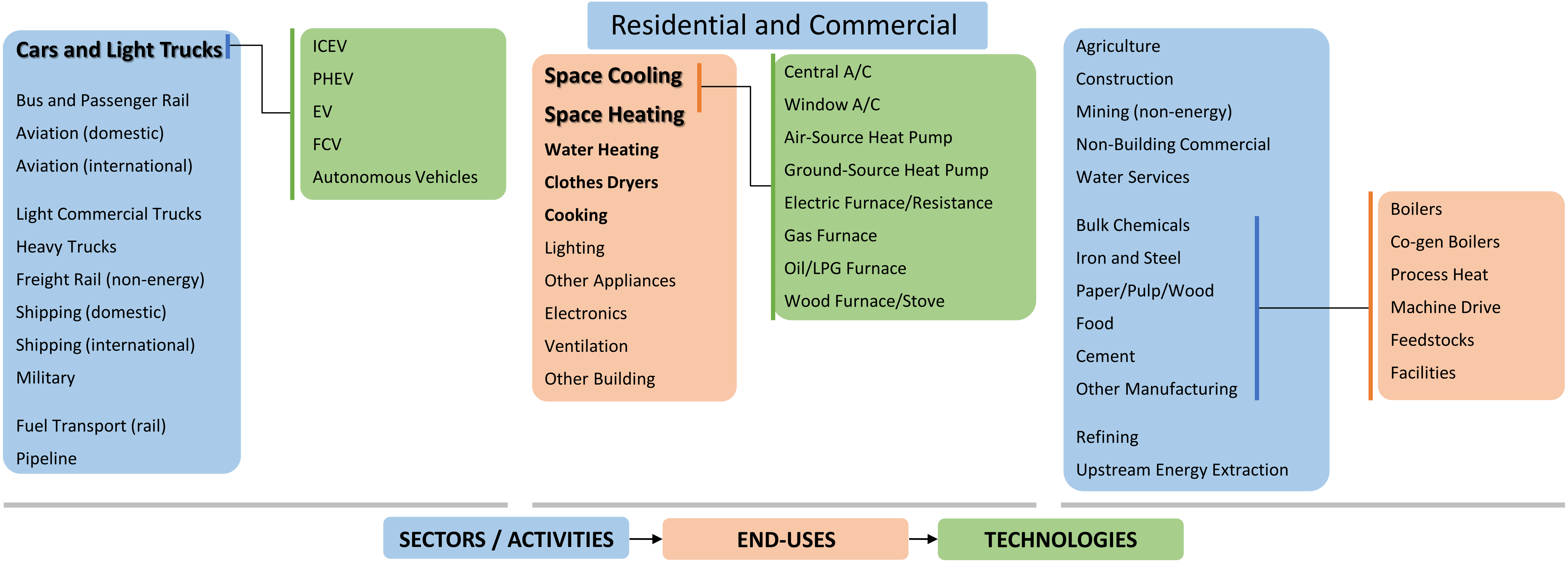
🟥	Geothermal	Resource supply constraints by state
🟩	Biomass	Cofiring or standalone; biomass supply curves from FASOM-GHG model
🟩	Bio CCS	Net CO_2 removal technology; updated cost and performance estimates from Generation in 2020
🟦	Hydro	Existing capacity endowment, no expansion

REGEN End-Use Model Level of Detail by Sector

Transportation

Buildings

Industry



Cars and Light Trucks

Bus and Passenger Rail
Aviation (domestic)
Aviation (international)

Light Commercial Trucks
Heavy Trucks
Freight Rail (non-energy)
Shipping (domestic)
Shipping (international)
Military

Fuel Transport (rail)
Pipeline

ICEV
PHEV
EV
FCV
Autonomous Vehicles

Residential and Commercial

Space Cooling
Space Heating
Water Heating
Clothes Dryers
Cooking
Lighting
Other Appliances
Electronics
Ventilation
Other Building

Central A/C
Window A/C
Air-Source Heat Pump
Ground-Source Heat Pump
Electric Furnace/Resistance
Gas Furnace
Oil/LPG Furnace
Wood Furnace/Stove

Agriculture
Construction
Mining (non-energy)
Non-Building Commercial
Water Services

Bulk Chemicals
Iron and Steel
Paper/Pulp/Wood
Food
Cement
Other Manufacturing

Refining
Upstream Energy Extraction

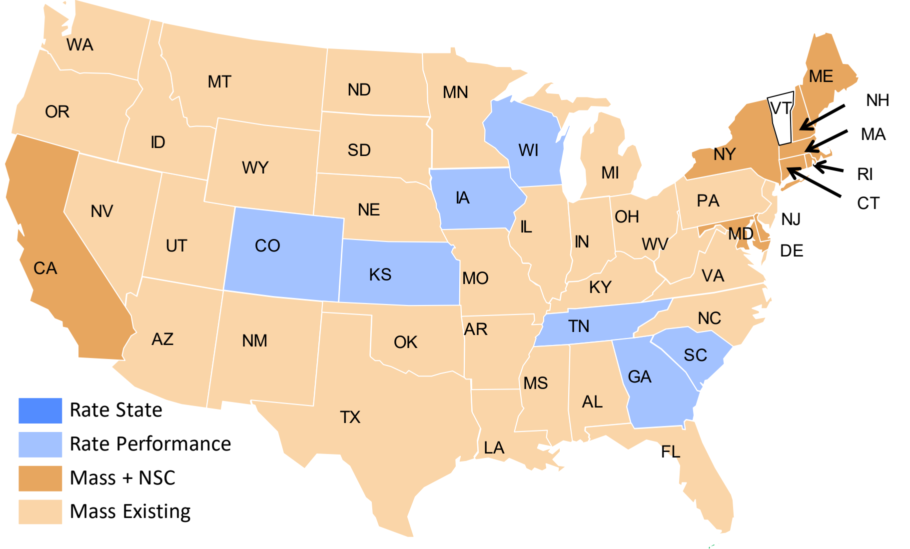
Boilers
Co-gen Boilers
Process Heat
Machine Drive
Feedstocks
Facilities

SECTORS / ACTIVITIES → **END-USES** → **TECHNOLOGIES**

Represents a Wide Range of Potential Environmental Policies at National, Regional, and State Level

- US-REGEN can represent a large variety of environmental policies

CO_2 Mass (Tons) Standards	Low Carbon Fuel Standards
CO_2 Rate Standards	Technology Mandates
Renewable Portfolio Standards (RPS)	Multi-state/region policies such as RGGI
Clean Energy Standards	CO_2 Taxes



- US-REGEN's national scope and state-level granularity allows us to represent multi-state markets and national environmental credit trading; focus on economics of renewables allows us to understand the costs of very stringent policies
- Most commercial IRP models focus only on RPS and CO_2 Taxes

Key New York Policies Captured in US-REGEN Reference

Technology Mandates

Battery Storage, Solar, and Offshore Wind mandates by state.

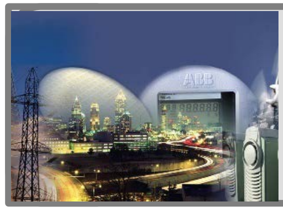
NY Senate Bill 6599—9GW offshore wind by 2035

Renewable Portfolio Standards

State targets are aggregated to regions as needed. Includes representation of eligible technologies by state, bundled and unbundled RECs, and alternative compliance prices. **NY Senate Bill 6599—70% RPS by 2030**

Carbon Pricing

California's AB32 (economy-wide carbon cap) is represented by a carbon price to the electric sector in this analysis.



State & Regional GHG/CO_2 Reduction Targets

Includes RGGI and state-based GHG/CO_2 reduction targets.

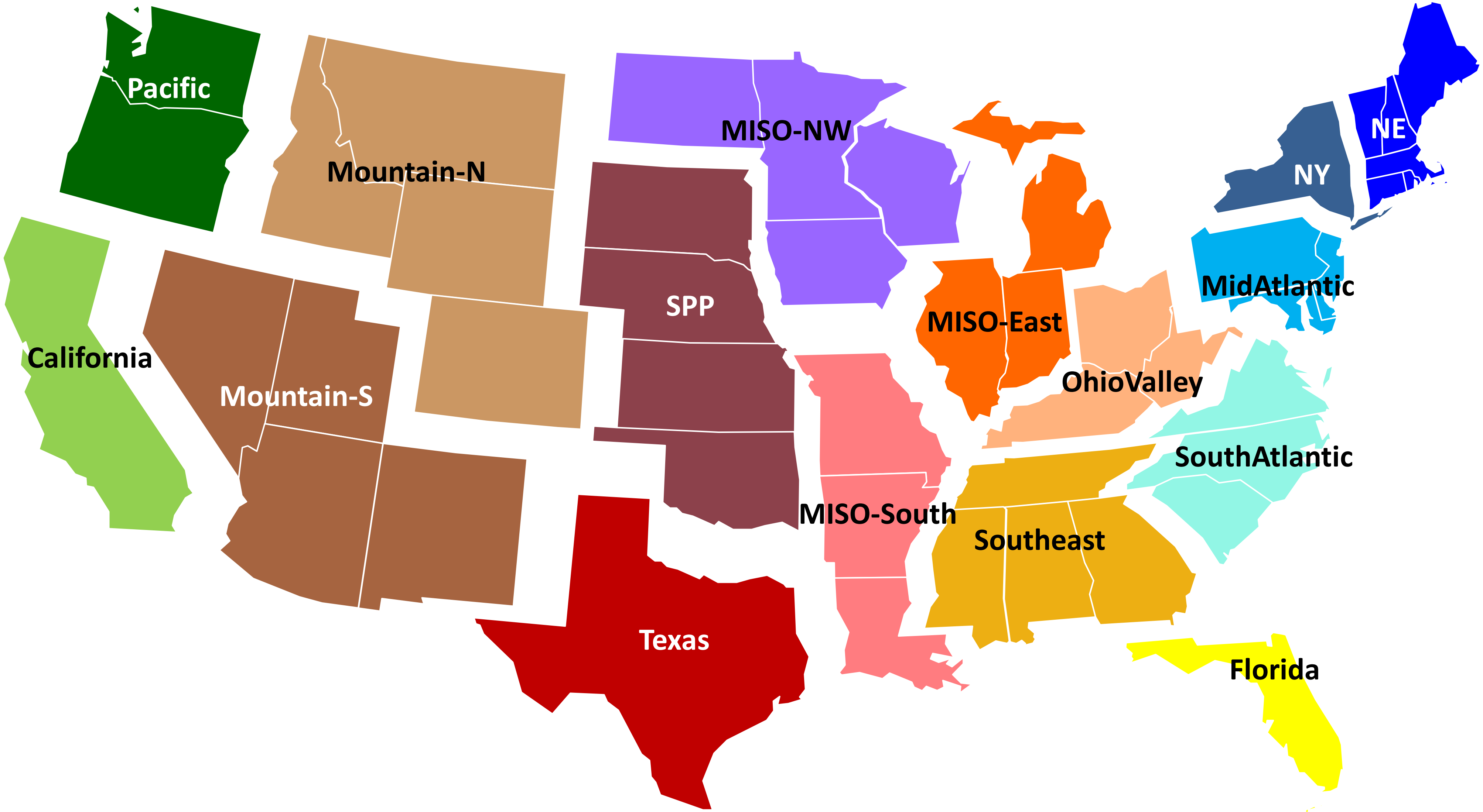
Clean Electricity Standards

Capture individual state clean electricity standards. Includes representation of eligible technologies, target type (retail or generation), and alternative compliance prices. No representation of ZEEC trading at this time. **NY Senate Bill 6599—100% zero CO_2 by 2040**

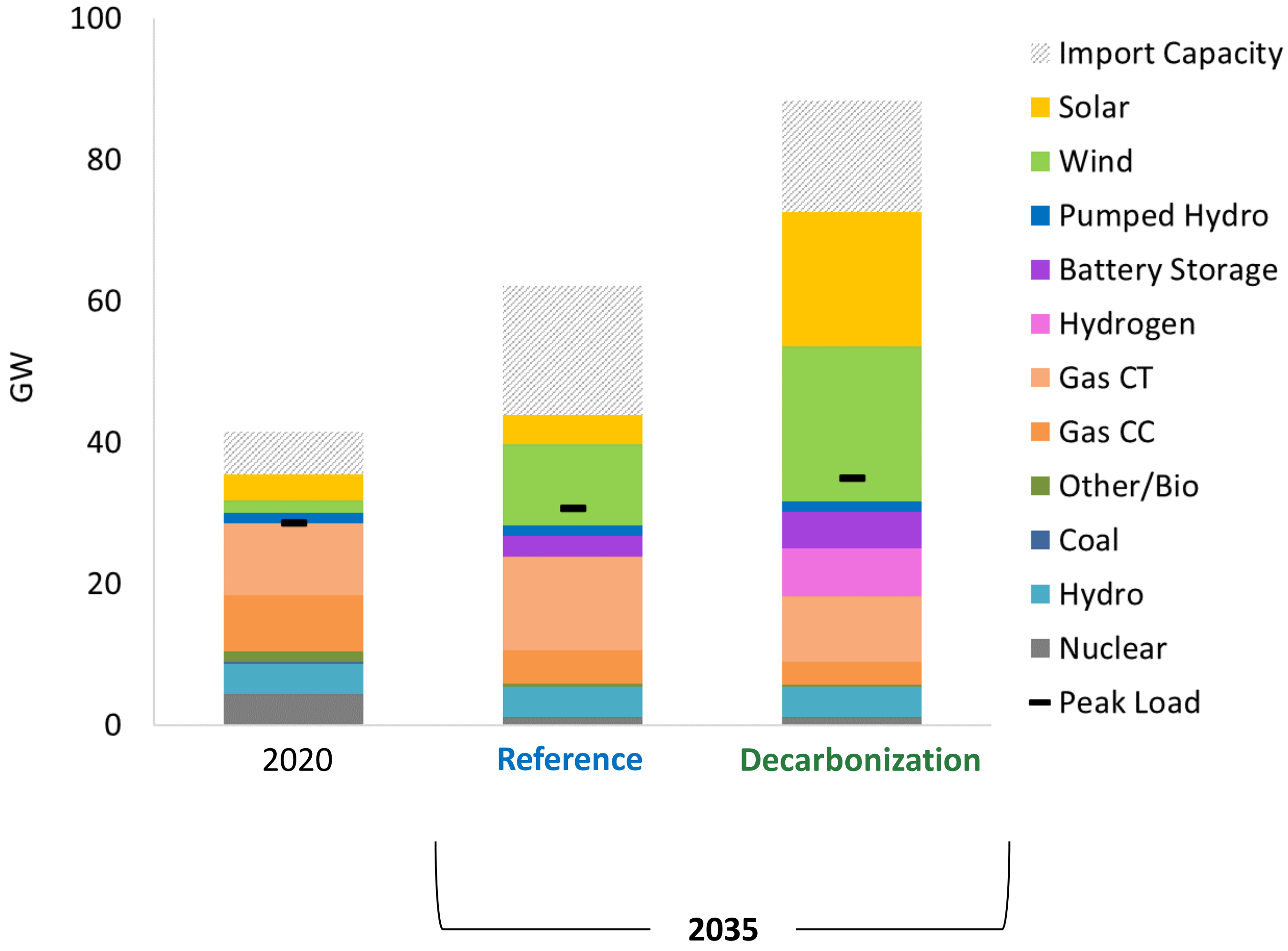
Additional Modeled Technology Tax Credits in Reference

- The Federal Production Tax Credit (PTC) for wind generation ($/MWh). This is phased out over time per the Consolidated Appropriations Act 2016 (Title III; Sec. 301)
  - Phased out after 2025
- The Federal Business Energy Investment Tax Credit (ITC) currently available for solar generation. This is reduced over time per the Consolidated Appropriations Act (Title III: Sec 303)
  - Scales down to 10% of capital cost in 2022
- 45Q tax credits for carbon capture have been assumed to be removed with adoption of economy-wide policy and are inactive

US-REGEN Regional Aggregation Used in this Study



Result: US-REGEN NY Installed Generation Capacity by Scenario



The modeled **Reference Scenario** portfolio shows:

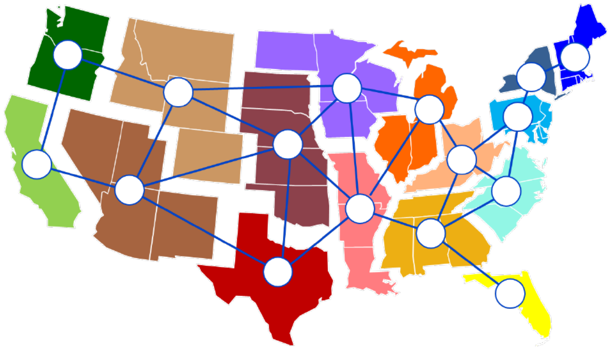
- Continued strong economics for gas
- Economic deployments for renewables (mostly wind)
- Modest role for short-duration batteries

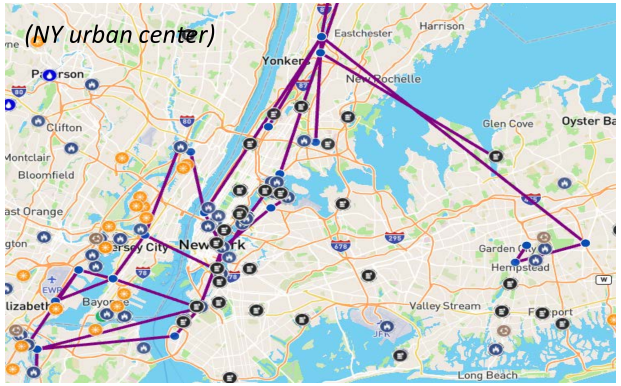
Compared to Reference, the modeled **Decarbonization Scenario** drives:

- Significantly higher wind
- Significantly higher utility-scale solar
- Electrolytic hydrogen-fired generation
- Additional and longer duration batteries (~20 hr)
- Earlier retirement of carbon emitting natural gas-fired generation

Nodal Capacity Expansion Modeling Objectives

- Detailed power system reliability studies benefit from each generating unit in a system being represented by its physical location and engineering/operating characteristics, and the transmission network lines between them and localized loads.
- We use Energy Exemplar's long-term capacity expansion planning model (PLEXOS-LT Plan) and inform it with US-REGEN scenarios to develop a power system model with the unit-level detail and system topology required for the system cost and reliability evaluations in this study.
- For this study, PLEXOS-LT Plan is configured as a nodal model, optimizing the generating capacity portfolio as a mixed integer program to site discrete units across nodes.





Regional technology planning models provide a critical starting point for detailed unit-level capacity expansion and operations-level analyses

Data & Assumptions Transfer Process to Link Regional Technology Pathways & Nodal Unit-Level CEP Models

Tool Agnostic

1. Identify Consistent Datasets and Assumptions
2. Select Key Input Datasets
3. Re-format and Re-Structure the Data
4. Align Key Spatial & Technology-Level Data between the Models
5. Align Other Key Exogenous System Conditions

Execute Nodal Planning and Operation Model

Data & Assumptions Transfer Process: US-REGEN & PLEXOS-LT

Tool-based Implementation
for each scenario

1

Identify Consistent Datasets and Assumptions

Compared temporal & spatial granularity, time series, and key underlying technology assumptions for:

- Load
- wind and solar profiles
- fuel costs
- technology VO&M costs
- technology FO&M costs
- existing capacity

2

Select Key Input Datasets

Applied US-REGEN
- end-use model developed loads
- wind and solar profiles
- EGU capital costs

Retained PLEXOS North American EIC dataset:
- site-specific fuel costs
- hydro profiles
- existing G&T capacity

3

Re-format and Re-Structure the Data

Modeled modified 3-pool system: NYISO + adjacent PJM and ISO NE zones

Develop Python script-based infrastructure to automate mapping and downscaling US-REGEN input data

4

Align Key Spatial & Technology-Level Data between the Models

Input US-REGEN outputs to PLEXOS-LT problem:
- Optimal generation capacities, applied as max new unit build constraints by technology
- Reserve margin, by region
- Electricity trade in/out of NY, applied as max transfer limits

5

Align Other Key Exogenous System Conditions

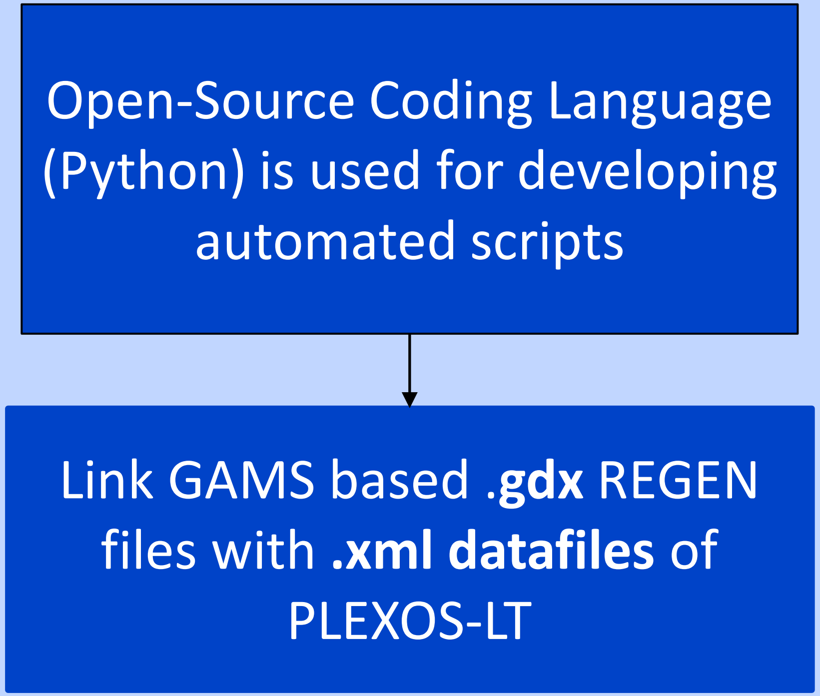
Input US-REGEN assumptions for:
- State RPS policies
- NY Clean Energy Standard policy

Retained PLEXOS dataset RGGI policy representation (shadow price)

Execute Nodal Planning and Operation Model

This project developed automated data transfer tools to integrate expansion planning tools of different structures and across different platforms

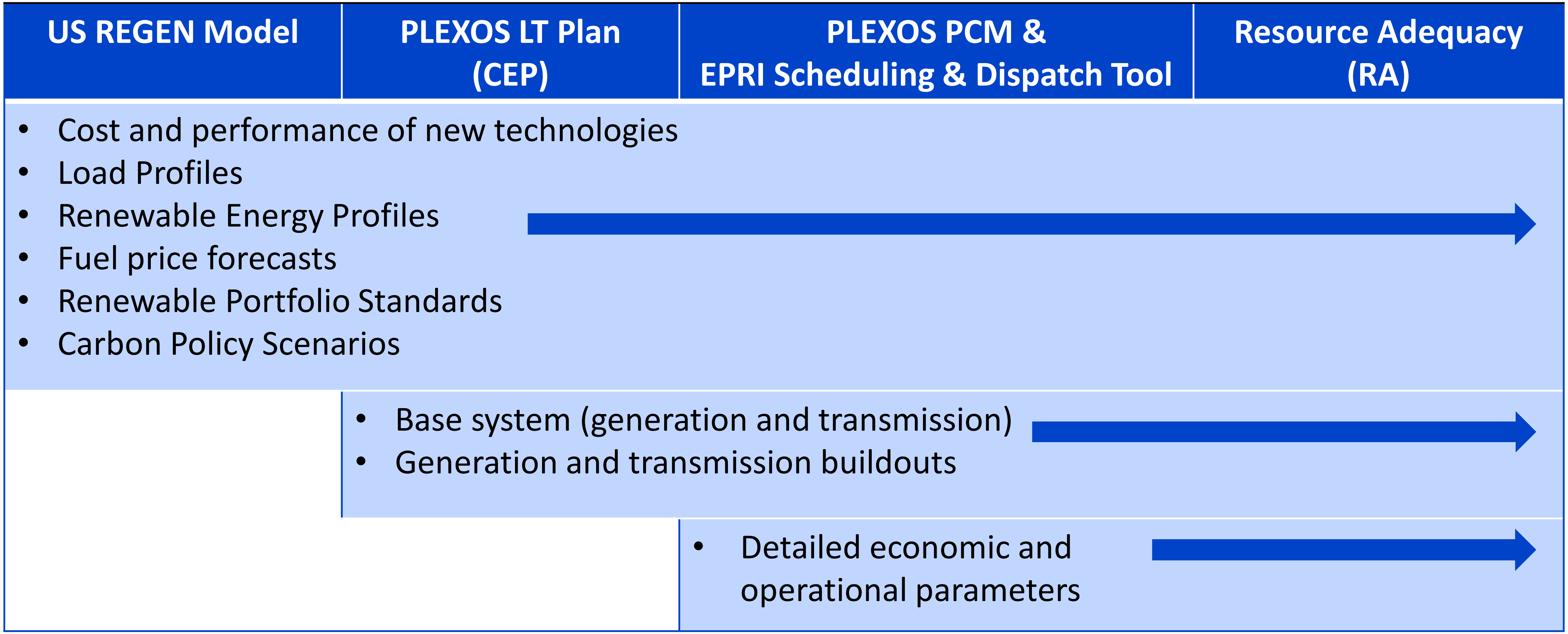
- Reduces **manual errors**
- Reduces **data handling time**
- Enables **data transferability**
- Enables **replicability**



Open-Source Coding Language (Python) is used for developing automated scripts

Link GAMS based **.gdx** REGEN files with **.xml datafiles** of PLEXOS-LT

Key Input Datasets and Assumptions Across the Models



US REGEN Model	PLEXOS LT Plan (CEP)	PLEXOS PCM & EPRI Scheduling & Dispatch Tool	Resource Adequacy (RA)

- Cost and performance of new technologies
- Load Profiles
- Renewable Energy Profiles
- Fuel price forecasts
- Renewable Portfolio Standards
- Carbon Policy Scenarios

- Base system (generation and transmission)
- Generation and transmission buildouts

- Detailed economic and operational parameters

US-REGEN Data Used in PLEXOS LT Plan

	US-REGEN Inputs & Outputs	PLEXOS-LT Inputs
Inputs	Candidate Generator Technologies	US-REGEN inputs are mapped and transferred to corresponding PLEXOS inputs
	Technology-Based Capital Costs	
	Technology-Based FOM & VOM Costs	
	Fuel Costs	
	Wind and Solar Profiles	
	RPS and CO_2 Policies (constraints)	
	Transmission Investment Costs	
	Transmission OM Costs	
Outputs	Optimal Generation Capacity (GW) by Technology	Upper and Lower Bounds on Candidate Generators (and Type)
	Optimal Inter-Regional Transmission Capacity*	Lower Bounds on Capacity Investments in T-Planning Model
	Electricity Demand (8760 Load) by Region/Zone	8760 Load for Study Region (utilizing existing PLEXOS LDFs)
	Regional (Wholesale) Electricity Transfers*	Upper and Lower Bounds on Transfers In/Out Study Region
	Reserve Margin (calculated endogenously)	Reserve Margin

* For the purposes of this demonstration study, US-REGEN scenario transmission investment and power flow results were not utilized in the nodal-level capacity expansion planning modeling. Future case studies will active these important additional results.

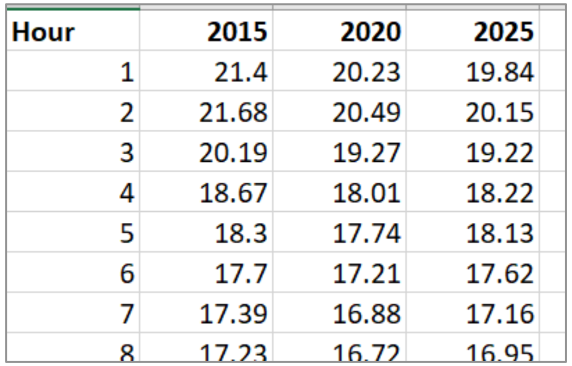
Aligning Spatial Load Data Between US-REGEN and PLEXOS LT Plan

Run US-REGEN integrated electric sector and end-use model

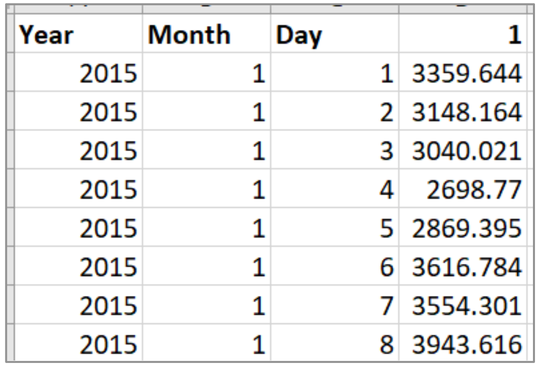
Reshape the load data into PLEXOS LT Plan format

Spatially map PLEXOS- LT plans zones to US-REGEN regions

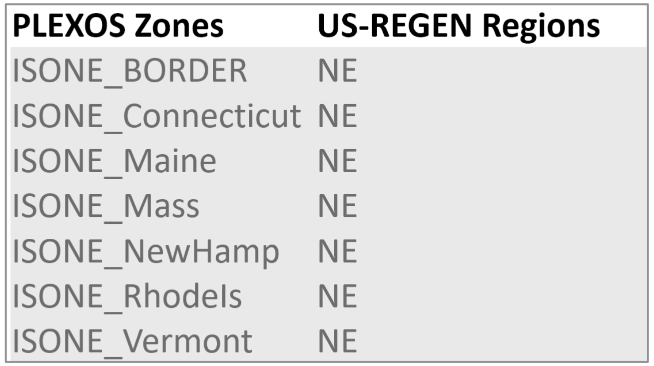
Disaggregate load data at nodal level utilizing existing PLEXOS Load distribution factors



Hour	2015	2020	2025
1	21.4	20.23	19.84
2	21.68	20.49	20.15
3	20.19	19.27	19.22
4	18.67	18.01	18.22
5	18.3	17.74	18.13
6	17.7	17.21	17.62
7	17.39	16.88	17.16
8	17.23	16.72	16.95



Year	Month	Day	1
2015	1	1	3359.644
2015	1	2	3148.164
2015	1	3	3040.021
2015	1	4	2698.77
2015	1	5	2869.395
2015	1	6	3616.784
2015	1	7	3554.301
2015	1	8	3943.616

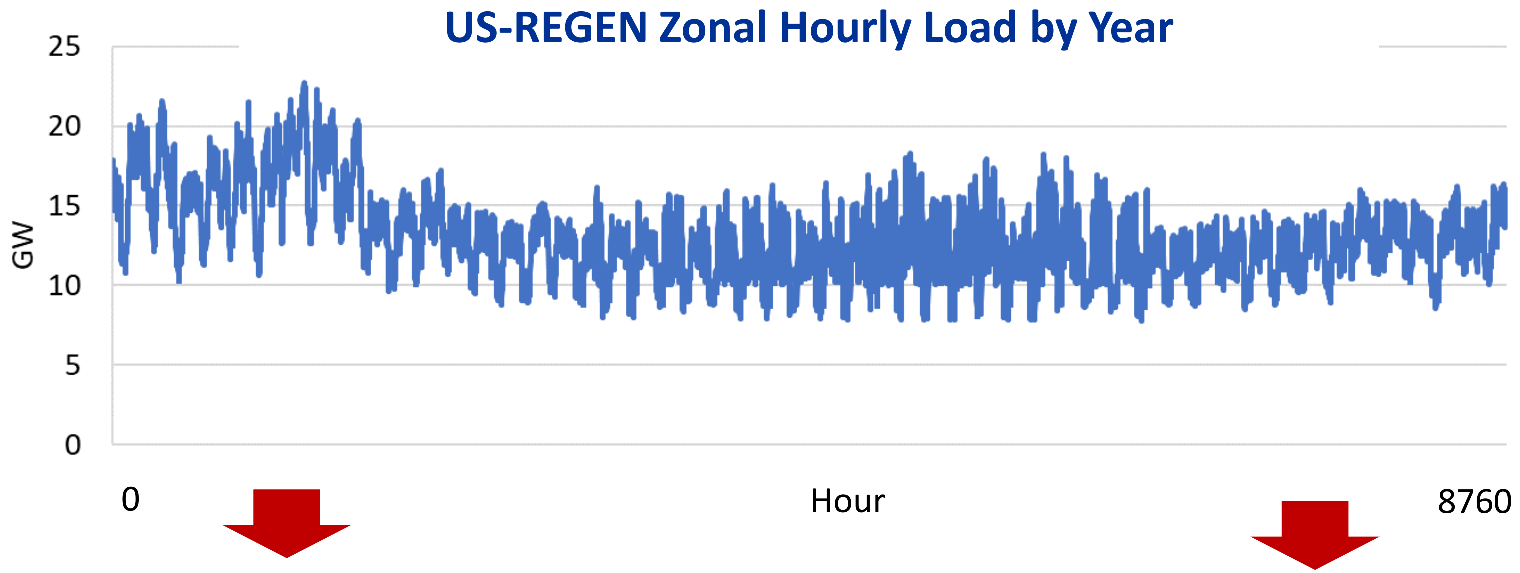


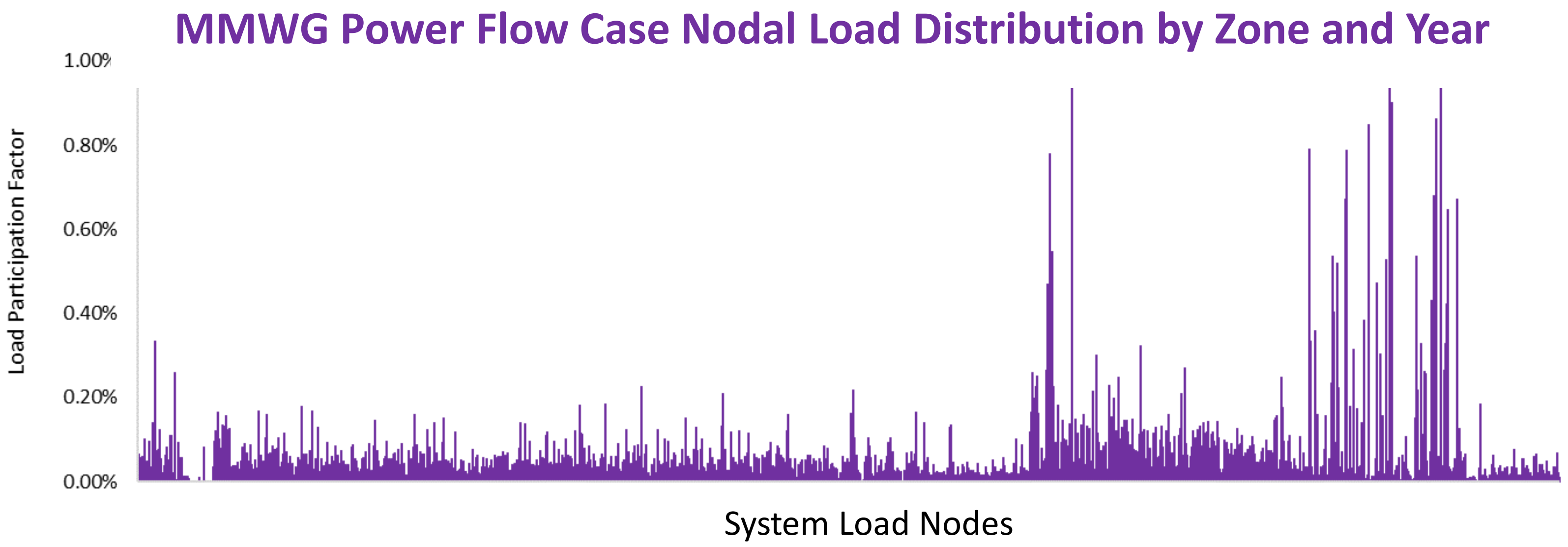
PLEXOS Zones	US-REGEN Regions
ISONE_BORDER	NE
ISONE_Connecticut	NE
ISONE_Maine	NE
ISONE_Mass	NE
ISONE_NewHamp	NE
ISONE_Rhodels	NE
ISONE_Vermont	NE

Data was interpolated to missing years preserving the shape of the load profile from US-REGEN

Disaggregating US-REGEN Zonal Load for Nodal Planning

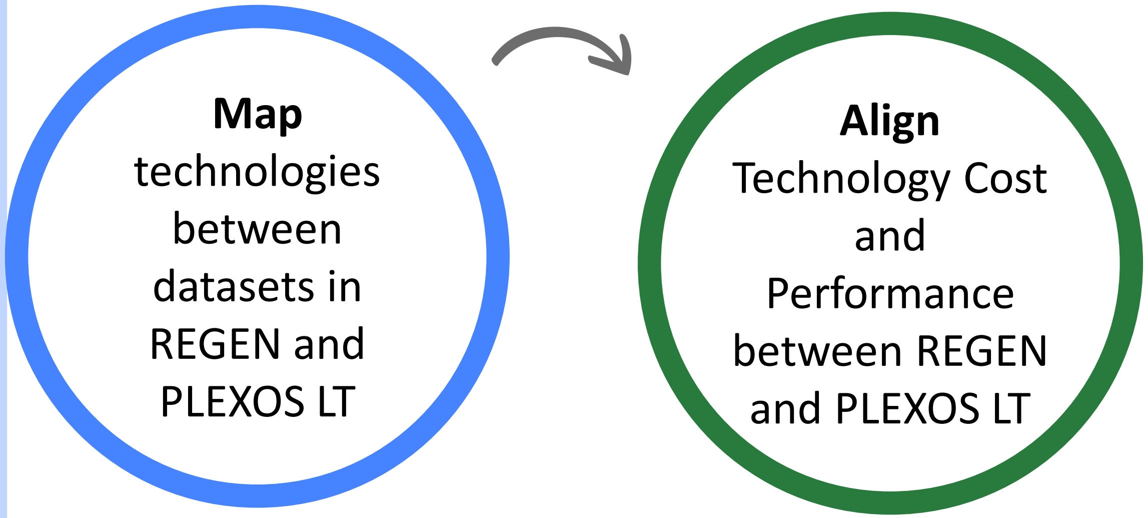
- Annual 8760 electricity loads are developed for each region/zone for the planning horizon using US-REGEN's end-use model.
- Loads consider scenario-based electrification, end-use technologies, and price response from electricity supply.
- US-REGEN zonal loads are allocated to each system load node using Load Participation Factors (LPFs)—345 to 34.5 kV
- LPFs are based on underlying MMWG scenario power flow cases, which consider historical load participation rates and adjustments over time for AC feasibility.


US-REGEN Zonal Hourly Load by Year


MMWG Power Flow Case Nodal Load Distribution by Zone and Year

Aligning Technology Data Between US-REGEN and PLEXOS LT Plan

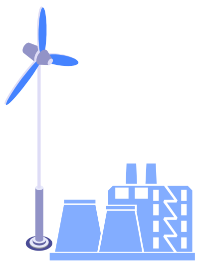
Technology Data



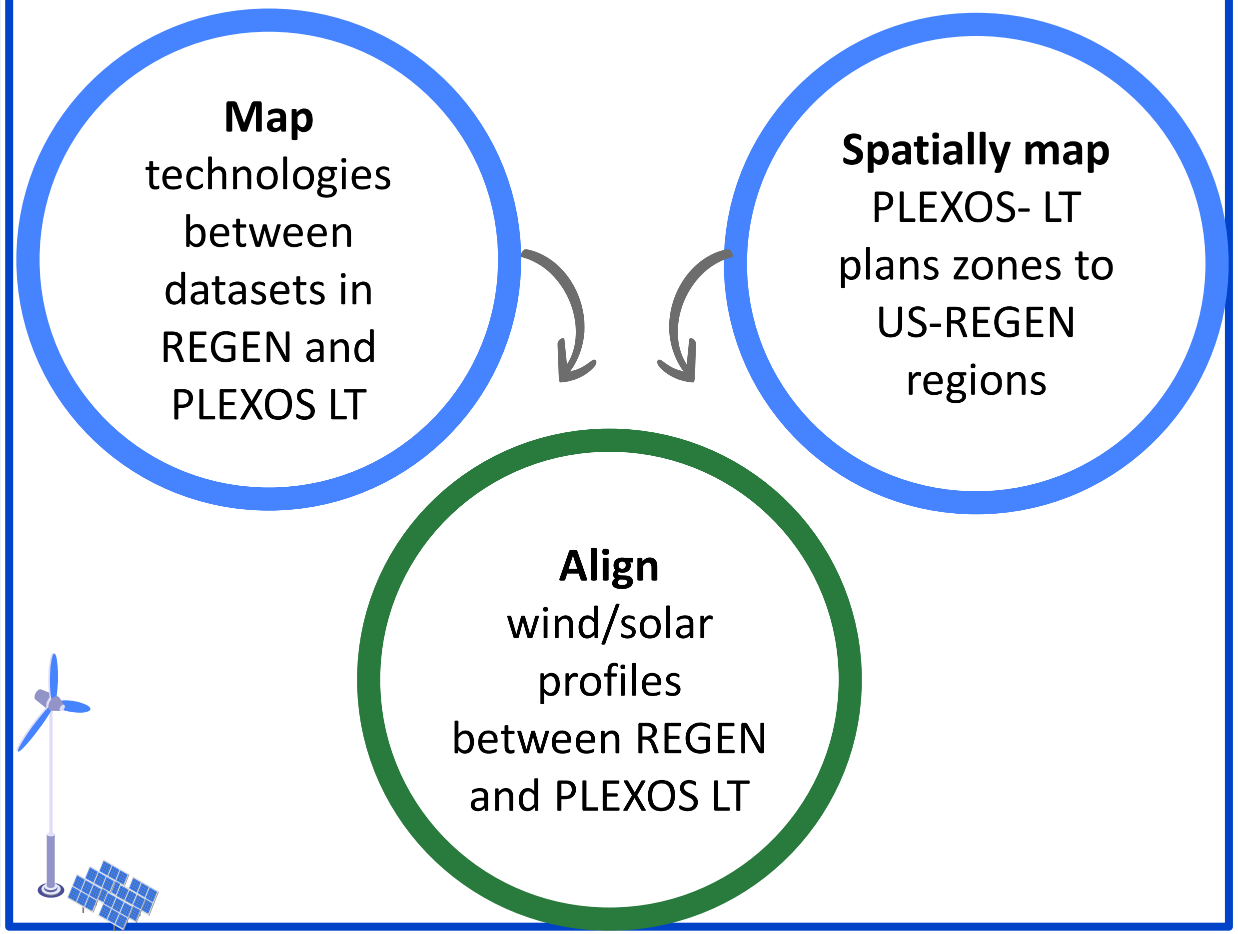
Map technologies between datasets in REGEN and PLEXOS LT

Align Technology Cost and Performance between REGEN and PLEXOS LT

US-REGEN	PLEXOS	Policy Scenario
ngcc-n	CCCT_NG	Ref
nggt-n	SCCT_NG	Ref
wind-n2	WT_WND	Ref
wind-n3	WT_WND	Ref
wnos-n2	WT_WND	Ref
pvsx-n4	PV_SUN	Ref



Technology and Spatial Data For Wind and Solar Profiles



Map technologies between datasets in REGEN and PLEXOS LT

Spatially map PLEXOS- LT plans zones to US-REGEN regions

Align wind/solar profiles between REGEN and PLEXOS LT

Siting Candidate Generation Technologies

NY is modeled as an island for capacity expansion in this demonstration study

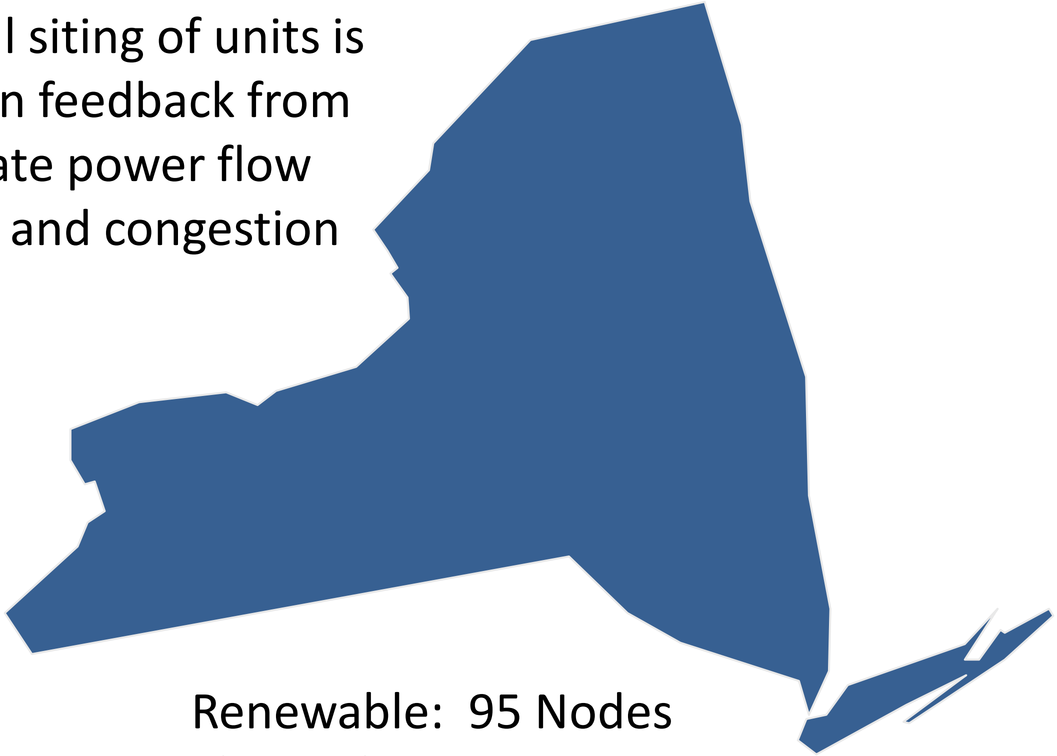
Thermal Units

Candidate units at higher voltage buses (>115KV)

Wind and Solar Units

Candidate units at higher voltage renewable potential buses (>115KV)

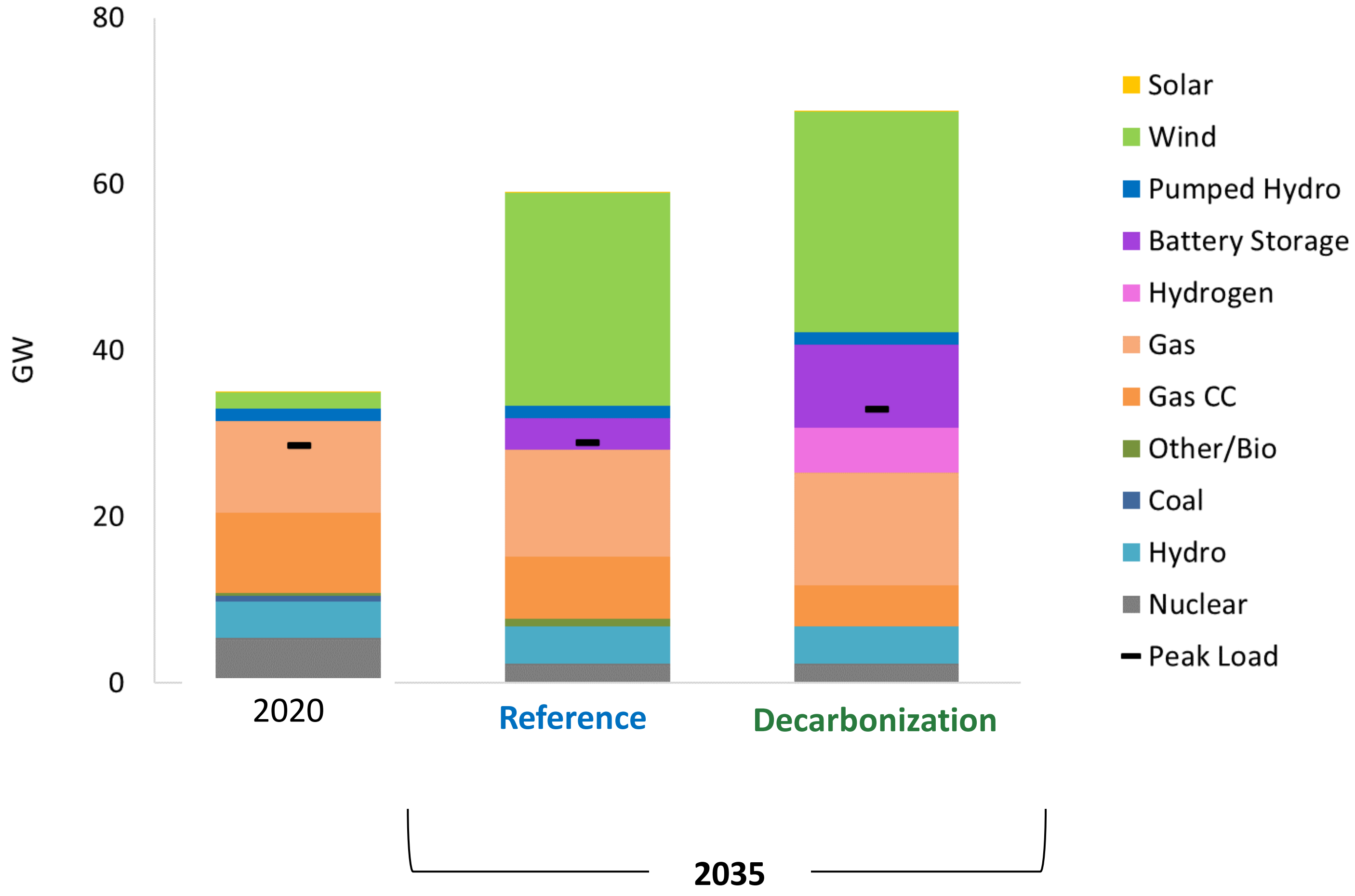
The final siting of units is based on feedback from a separate power flow analysis and congestion analysis



Renewable: 95 Nodes
Thermal: 33 Nodes
Transmission Upgrades: 30 Nodes

Result: PLEXOS LT Plan NY Installed Capacity* by Scenario

*These portfolios represents the <u>initial</u> resource expansion plan, prior to information feedback from reliability analyses



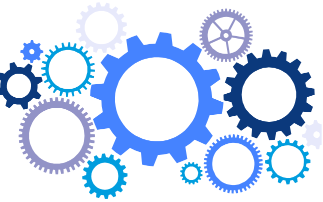
Re-optimizing the resource portfolio at the unit-level and across a nodal transmission network drives:

A **Reference portfolio** with
- Significant new on and off-shore wind
- New short-duration batteries
- Continued reliance on natural gas

A **Decarbonization portfolio** with
- Significant new on and off-shore wind
- Significant *long-duration* batteries
- New electrolytic H_2-fired generation
- Natural gas (slightly lower than Reference)

There is significantly more wind and less solar in the PLEXOS portfolios than in the US-REGEN scenarios used as a starting point. Key drivers:
- Demonstration study PLEXOS scenarios represent NY as an “island,” and net-import capacity is replaced by new wind
- Nodal buses support significantly more offshore wind, reducing need for less economic solar

Top 5 Challenges in Linking Technology Pathways & Capacity Expansion Planning Models



Spatially mapping of resources and technologies at specific nodes may need to be frequently altered between iterations based on the feedback from PCM and transmission power flow analysis.

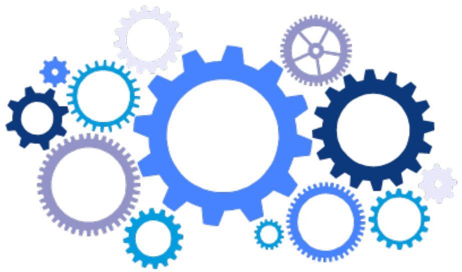
Consistent assumptions across the integrated process may require different structuring of constraints in different tools within their limitations.

Technology characteristics for new technologies, such as hydrogen and storage, are represented within the limitations of what is available in the commercial tools.

The temporal resolution may differ between bulk capacity expansion and other operational tools. Choosing appropriate representative days could reduce the iterations between planning and operation tools.

Infeasibilities and data conflicts during the integration process can be reduced by having a structured data pipeline, prior evaluation of computational resources, and calibrating the base data in each tool for consistent assumptions across the tools.

Key Methodological Takeaways



Structured data pipeline between tools reduces manual errors, data handling time, and improves data transferability, transparency, and replicability

Evaluation of the computational resources is crucial to defining the scope, timeline of the project, and for planning the distribution of resources amongst the teams

Identification of key metrics helps defining the linkages between tools, and for identifying key output variables as part of the analysis.

Initial linking process includes multiple iterations of running tools

KEY INSIGHTS

Linking Technology Pathways Models & Nodal Capacity Expansion Planning Models

There are multiple tradeoffs between spatial vs. temporal granularity in datasets when moving from a zonal technology-level model to a nodal unit-based model.

Linking zonal technology planning & nodal CEP models requires large volumes of data management & transfer.

The overall framework is tool agnostic, but differences in model structure, operating systems, and data management software make implementation of the framework heavily tool dependent.

2

Improving Capacity Expansion Portfolios with Resource Adequacy and Operational Reliability Evaluations

2 Improving Capacity Expansion Portfolios with Resource Adequacy and Operational Reliability Evaluations

Objective

- To link capacity expansion planning (CEP) with production cost and resource adequacy evaluations.
- To evaluate system build-outs developed by the CEP model in more detail to verify they meet critical economic, reliability, environmental, and operational goals.
- Verify input assumptions in the CEP model scenarios remain valid
  - Planning reserve margin, capacity credit, O&M costs, etc.
- Confirm that the system remains reliable across different futures by performing additional sensitivities
  - Fuel prices, outages rates, weather years, etc.

Model Comparisons

	Capacity Expansion (PLEXOS CEP)	Production Cost Model (PLEXOS PCM)	Resource Adequacy (PLEXOS RA)
Objective	Optimize the system buildout to minimize operating and build costs	Optimize operation of supply resources to reduce costs and maintain reliability	Determine the ability of the system to meet load under many scenarios
Horizon	Long horizons 10 -30 years	1-year horizons most common	1-year horizons
Temporal Resolution	Representative hours or days, to reduce run times	Hourly or sub hourly resolution	Hourly resolution • Monte Carlo outages, weather years, load levels
Operational Details and other inputs	Common model for generation, transmission, load, fuels, emissions • Build candidates added • Moderate operational details added	Common model for generation, transmission, load, fuels, emissions • Operational details added (e.g., ramp rates, start-up time, heat rate curves)	Common model for generation, transmission, load, fuels, emissions • Detailed outages added • Simplified operational details

PLEXOS LT Plan → PLEXOS PCM & RA Modules Data Flow

	PLEXOS LT Plan	PLEXOS PCM	PLEXOS RA
Inputs	Common base system (generation and transmission)	Common base system (generation and transmission)	Common base system (generation and transmission)
	Hourly load and RE forecasts	Hourly and sub-hourly load and RE forecast	Hourly load and RE forecast for multiple weather years
	Fuel price forecasts	Fuel price forecasts	Fuel price forecasts
	Policies	Policies	Policies
	Candidate generators and transmission	Detailed economic and operational parameters	Detailed outage parameters
		Generation and transmission buildouts	Generation and transmission buildouts
Key Outputs	Generation and transmission buildouts	Detailed unit commitment and dispatch patterns	LOLE/LOLP
	System build costs	System and unit operating costs	Capacity contribution
	System operating costs	Emissions	Planning reserve margin needs
	Emissions	Operational reliability and transmission usage	

Common Assumptions

Key Adequacy and Reliability Evaluation Metrics

Resource Adequacy Assessments

- **Standard Reliability Metrics:**
  - Loss of Load Probability (LOLP)
  - Loss of Load Expectation (LOLE)
  - Expected unserved energy
  - Hours unserved energy
- **Reliability Metrics directly included in CEP:**
  - Expected load carrying capacity (ELCC)
  - Target planning reserve margin
- **Potential:**
  - Common cause outages
  - High risk states

Production Cost Modeling

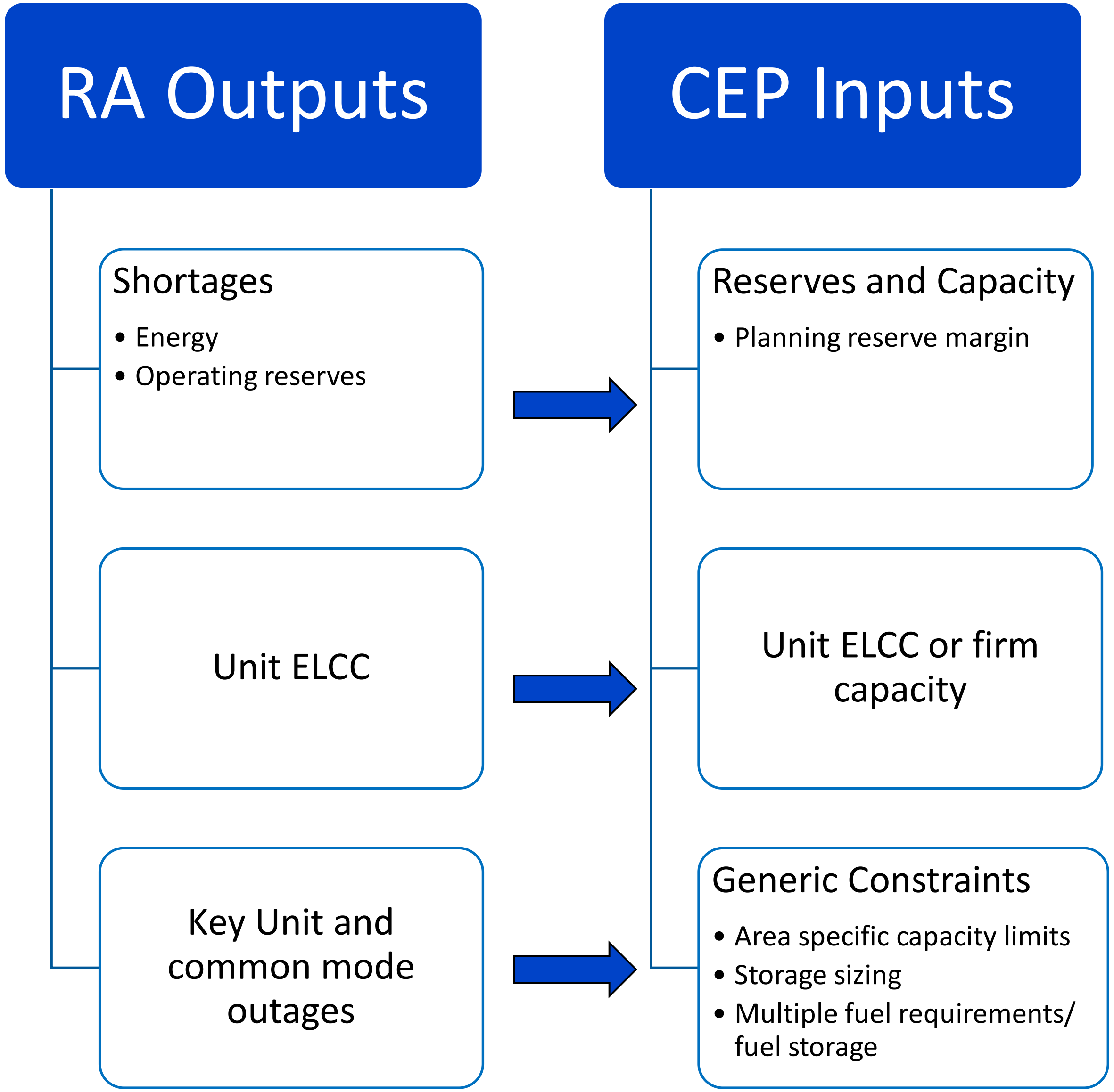
- **Economic Metrics:**
  - System costs (generators, fuels, congestion, etc.)
  - LMP, short run profits
- **Reliability Metrics:**
  - Unserved energy/reserve shortage
  - Generator starts/stops, ramping
  - Line flows and congestion
- **Operation Metrics:**
  - Emissions
  - Fuel usage
- Any metrics important to the specific system

Resource Adequacy Model Assumptions

- NYISO Area only
- Annual runs with 1-hour resolution
- 24-hour optimization steps
- Monte Carlo generator outages
  - 200 draws base, adjusted depending on convergence
  - Scenario reduction algorithm to optimize
- Same base database as CEP and PCM models
- Reduced detail to speed runs
  - Zonal transmission
  - Simplified heat rates
  - Reduced environmental controls
  - Linear Optimization

Opportunities for RA Assessment Feedback to CEP

- RA models simulate operation of the system under many different conditions
- Effective load carrying capacity (ELCC) of resources varies with the system buildout
  - Wind, solar, batteries have declining contributions with higher penetrations
  - Direct input to CEP, contribution to PRM depends on the build out
- Key units and common mode outages– any shortages that may need additional fortification or special rules that can be linked to specific units or causes
  - Units in load pockets
  - Units are dependent on same fuel supply
- RA needs map relatively directly to CEP inputs (more so than PCM outputs)
  - **This study applies Planning Reserve Margin (PRM) and storage unit adjustments (see next slides)**



RA Outputs

CEP Inputs

Shortages
- Energy
- Operating reserves

Reserves and Capacity
- Planning reserve margin

Unit ELCC

Unit ELCC or firm capacity

Key Unit and common mode outages

Generic Constraints
- Area specific capacity limits
- Storage sizing
- Multiple fuel requirements/ fuel storage

Production Cost Model (PCM) Assumptions

Hourly PCM

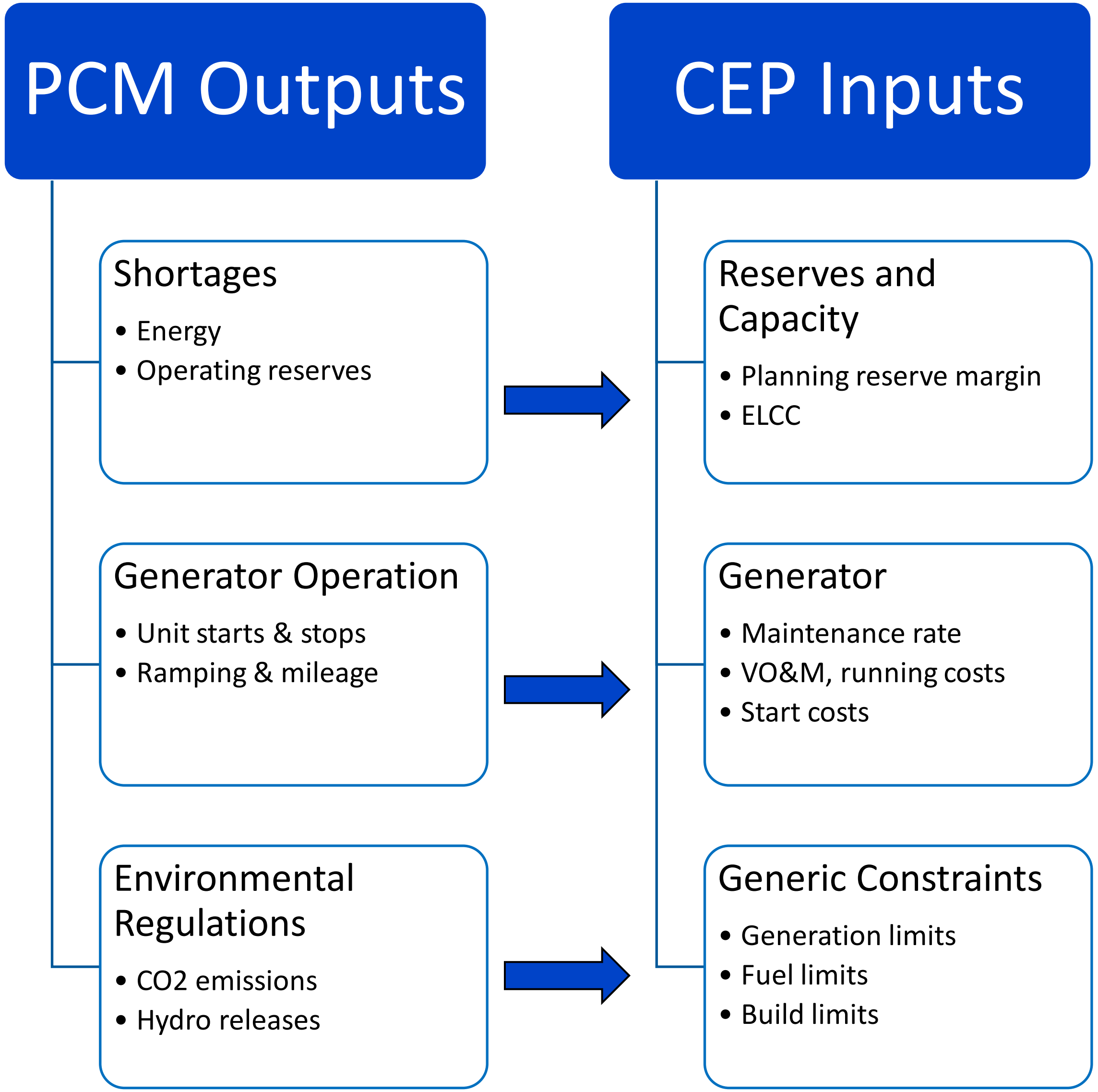
- Large Geographic area with full nodal transmission
  - Entire eastern interconnection (very resource intensive)
  - Northeast regions (NYISO, PJM, ISONE, IESO) to improve run times
- Annual runs with hourly resolution, target 2035 study year
  - 24-hour optimization steps
- Buildouts from CEP added
- Emissions and environmental policies enforced
- Mixed Integer Programing

Sub Hourly

- NYISO only, nodal transmission
  - Intertie flows imported from hourly run
- 2 Stage model runs for selected periods, Approximate actual operations processes
  - Hourly unit commitment run with forecast error for load, wind, and solar
    - Binding commitments and advisory dispatches
  - 10-minute resolution with hourly optimization steps
    - Redispatches committed units from hourly simulations to 10-minute actual profiles
    - Quick start units able to be committed
- Buildouts from CEP added
- All detail from hourly runs

Opportunities for PCM Feedback to CEP

- PCM provides a more detailed look at the system and operations than the CEP model can
  - Time compression and less operational detail in CEP model limits accuracy of some results
- The PCM may not be able to meet all constraints even if it did in CEP
  - Example: operating reserve requirements
- The adjustments to the CEP Inputs don’t correspond 1 to 1 with PCM outputs
  - Adjust build decisions to meet requirements even when it can’t resolve the requirements directly
  - Consider economic transmission upgrades due to congestion
- **This study recommends new candidate economic transmission line upgrades in the CEP to mitigate the variation in prices across the region (see next slides)**



PCM Outputs

Shortages
- Energy
- Operating reserves

Generator Operation
- Unit starts & stops
- Ramping & mileage

Environmental Regulations
- CO2 emissions
- Hydro releases

CEP Inputs

Reserves and Capacity
- Planning reserve margin
- ELCC

Generator
- Maintenance rate
- VO&M, running costs
- Start costs

Generic Constraints
- Generation limits
- Fuel limits
- Build limits

Result: RA—Planning Reserve Assessment

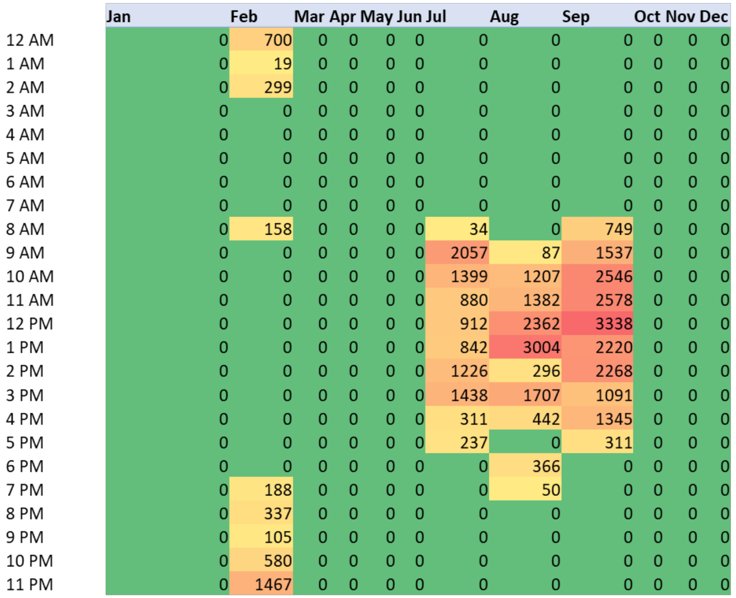
- The RA analysis calculates target reliability metrics (e.g., LOLE) and informs whether the planning reserve margin may need to be increased
- This analysis, performed via a Monte Carlo analysis in PLEXOS shows that **neither the initial Reference nor Decarbonization scenario portfolio met the typical NERC applied LOLE standard of 0.1 in 2035**

Metric	Initial Reference Portfolio	Initial Decarbonization Portfolio
Loss of Load Hours (hours)	243	216
Loss of Load Expectation (Days per Year)	0.20	0.18
Loss of Load Probability (%)	0.055	0.049
Expected Unserved Energy (ppm)	25.7	240.9
Loss of Load Events	71	71

Result: RA—Planning Reserve Assessment (continued)

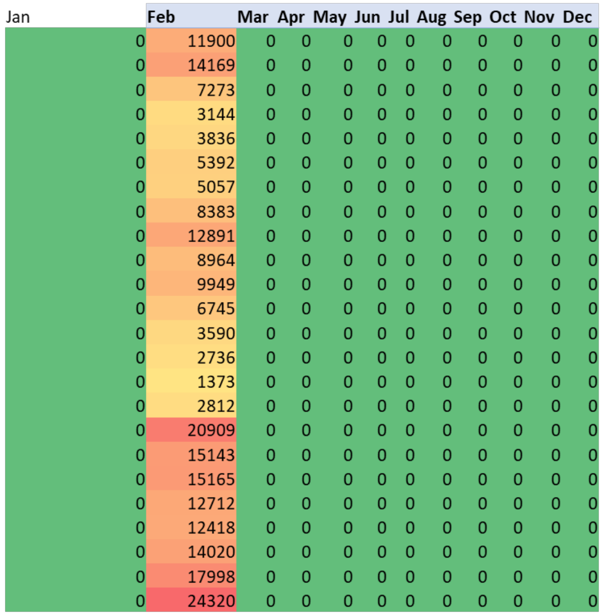
- Unserved energy across all Monte Carlo samples also shows periods of risk to the system under both scenarios (see adjacent heat maps)
  - Summer peaks had highest risk (e.g, high load, low wind) in the Reference scenario
  - Winter nights (e.g., High load due to heating loads) had highest risk in the Decarbonization scenario
- This RA analysis provided recommended updates to planning reserve margin in the capacity expansion

Reference Scenario



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
12 AM	0	700	0	0	0	0	0	0	0	0	0	0
1 AM	0	19	0	0	0	0	0	0	0	0	0	0
2 AM	0	299	0	0	0	0	0	0	0	0	0	0
3 AM	0	0	0	0	0	0	0	0	0	0	0	0
4 AM	0	0	0	0	0	0	0	0	0	0	0	0
5 AM	0	0	0	0	0	0	0	0	0	0	0	0
6 AM	0	0	0	0	0	0	0	0	0	0	0	0
7 AM	0	0	0	0	0	0	0	0	0	0	0	0
8 AM	0	158	0	0	0	0	34	0	749	0	0	0
9 AM	0	0	0	0	0	0	2057	87	1537	0	0	0
10 AM	0	0	0	0	0	0	1399	1207	2546	0	0	0
11 AM	0	0	0	0	0	0	880	1382	2578	0	0	0
12 PM	0	0	0	0	0	0	912	2362	3338	0	0	0
1 PM	0	0	0	0	0	0	842	3004	2220	0	0	0
2 PM	0	0	0	0	0	0	1226	296	2268	0	0	0
3 PM	0	0	0	0	0	0	1438	1707	1091	0	0	0
4 PM	0	0	0	0	0	0	311	442	1345	0	0	0
5 PM	0	0	0	0	0	0	237	0	311	0	0	0
6 PM	0	0	0	0	0	0	0	366	0	0	0	0
7 PM	0	188	0	0	0	0	0	50	0	0	0	0
8 PM	0	337	0	0	0	0	0	0	0	0	0	0
9 PM	0	105	0	0	0	0	0	0	0	0	0	0
10 PM	0	580	0	0	0	0	0	0	0	0	0	0
11 PM	0	1467	0	0	0	0	0	0	0	0	0	0

Decarbonization Scenario

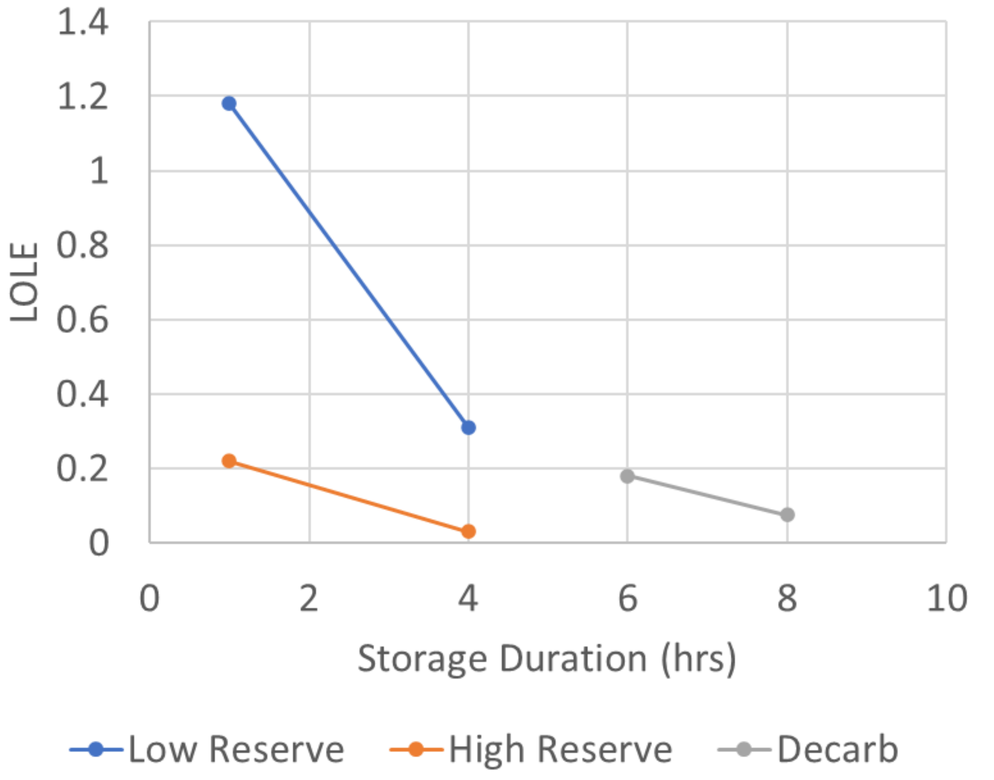


Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	11900	0	0	0	0	0	0	0	0	0	0
0	14169	0	0	0	0	0	0	0	0	0	0
0	7273	0	0	0	0	0	0	0	0	0	0
0	3144	0	0	0	0	0	0	0	0	0	0
0	3836	0	0	0	0	0	0	0	0	0	0
0	5392	0	0	0	0	0	0	0	0	0	0
0	5057	0	0	0	0	0	0	0	0	0	0
0	8383	0	0	0	0	0	0	0	0	0	0
0	12891	0	0	0	0	0	0	0	0	0	0
0	8964	0	0	0	0	0	0	0	0	0	0
0	9949	0	0	0	0	0	0	0	0	0	0
0	6745	0	0	0	0	0	0	0	0	0	0
0	3590	0	0	0	0	0	0	0	0	0	0
0	2736	0	0	0	0	0	0	0	0	0	0
0	1373	0	0	0	0	0	0	0	0	0	0
0	2812	0	0	0	0	0	0	0	0	0	0
0	20909	0	0	0	0	0	0	0	0	0	0
0	15143	0	0	0	0	0	0	0	0	0	0
0	15165	0	0	0	0	0	0	0	0	0	0
0	12712	0	0	0	0	0	0	0	0	0	0
0	12418	0	0	0	0	0	0	0	0	0	0
0	14020	0	0	0	0	0	0	0	0	0	0
0	17998	0	0	0	0	0	0	0	0	0	0
0	24320	0	0	0	0	0	0	0	0	0	0

Result: RA—Storage Assessment

- Because the initial Reference Scenario resource portfolio failed to meet the LOLE standard criteria, a separate sensitivity of the RA study was performed to identify potential changes in the storage configuration of the system
  - For the Reference Scenario, all 1-hour batteries replaced with 4-hour batteries of the same size at two different reserve margins (the initial Reference Scenario resource portfolio considered only 1-hour candidate batteries)
  - For the Decarbonization Scenario, 6-hour batteries were replaced with 8-hour
- RA metrics were calculated for each variation of the system
- **Results show the effectiveness of increasing battery duration on LOLE**

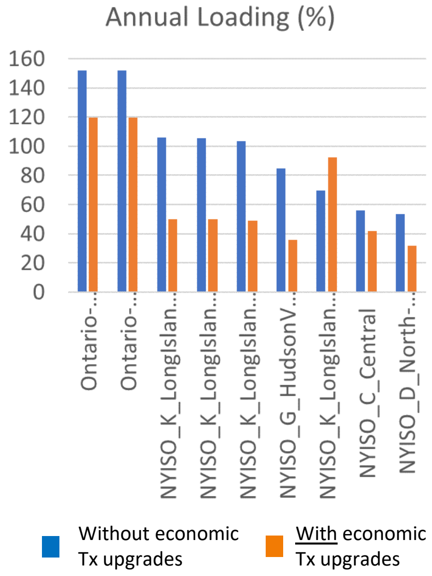
Effect of battery storage duration on system reliability

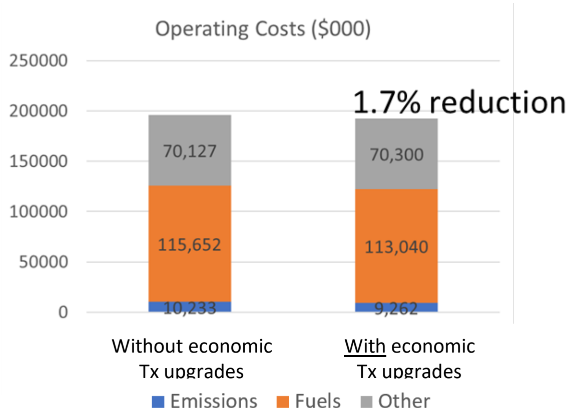


Low and High Reserve "cases" shown for Reference Scenario; only a High Reserve case is shown for the Decarbonization scenario.

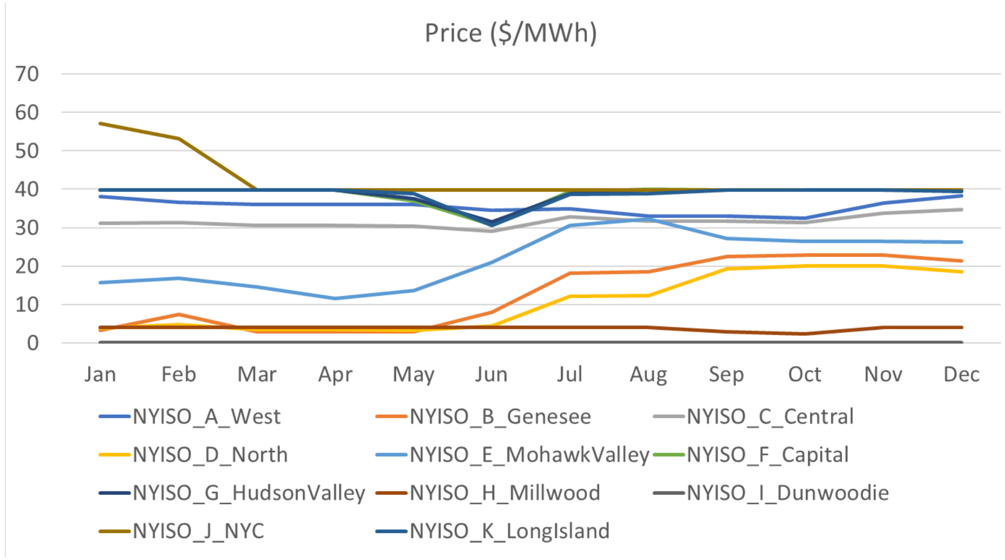
Result: PCM Transmission Network Congestion Assessment

- While detailed power flow analysis is necessary for reliability analysis, PCMs can provide important economic insights into transmission system.
- A congestion analysis was performed on both scenarios’ initial resource portfolios (without transmission expansion) to identify potential opportunities for economic transmission expansion.
  - **The 8760 simulation shows several lines that are congested throughout the full year (not only peak periods), some with excessive overloading.**
  - **Significant congestion-driven price differences were also observed between the NYISO zones (bottom graphic).**
- Reducing congestion allows less expensive energy to serve more load reducing system costs; the most congested lines were given economic upgrade options in the CEP model, to develop the final portfolios.



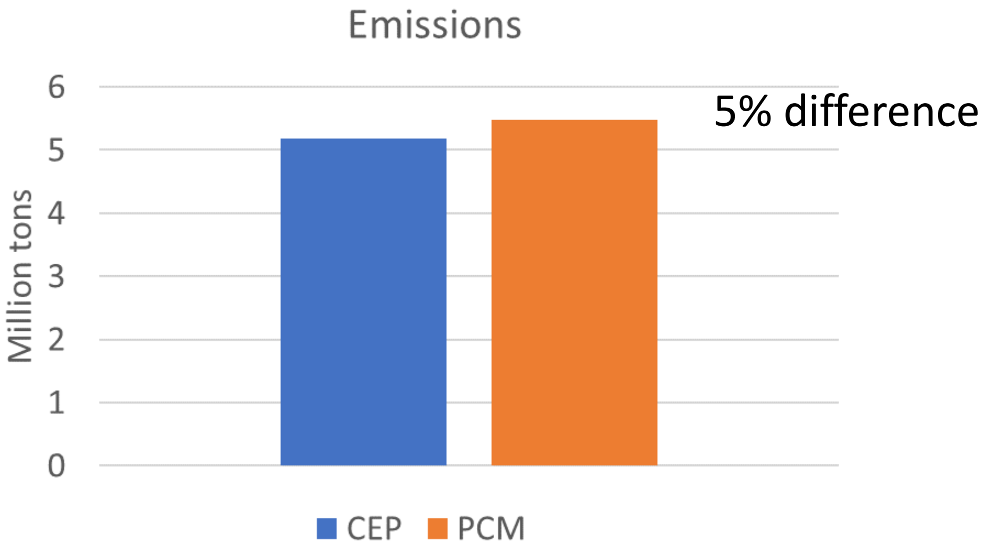


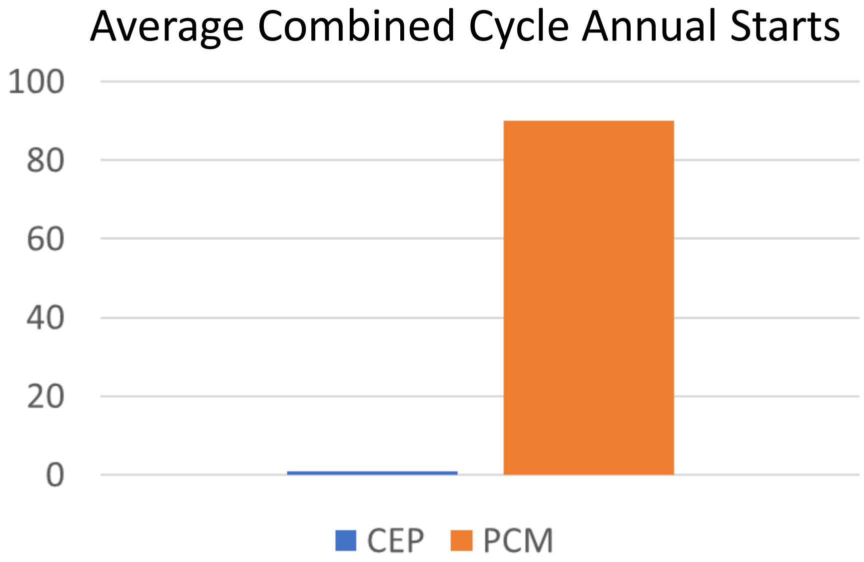
*Results are from the Decarbonization Scenario before and after the final capacity expansion iterations with economic transmission upgrades, shown here for illustration purposes



Result: PCM and CEP comparisons

- The PCM and CEP models have mostly identical inputs
- It is important to compare PCM outputs to CEP to ensure the CEP is working correctly
- Some assumptions cannot be directly mapped from one simulation to another, but can often still be included by other means
  - Example: Start costs from PCM could be transferred to VO&M in CEP
- CEP is better with average conditions, but tends to overweight or underweight conditions that occur in the tails impacting overall results
- The granularity differences will impact the outputs differently
  - Some outputs may be very similar (>10 % difference)
    - Examples: annual costs, fuel usage, emissions
  - Some output may be very different
    - Examples: generator starts, ramping, congestion
  - Specific outputs will depend on the system and assumptions
- Results may have persistent bias differences between PCM and CEP, requiring bias in the constraints
    - Example: emissions limits





KEY INSIGHTS

Improving Capacity Expansion Portfolios with Resource Adequacy and Operational Reliability Evaluations

Traditional PCM and RA modeling remain valuable to system planning.

Data management and validation continues to be a challenge across model types, even with a common software platform. Even shared data may require different levels of detail depending on the simulation.

Scoping each simulation can help save time and effort; this can include time horizon, time step, and geography needs.

Balance between simulation detail, run time, and post processing effort is essential; more detailed simulations aren't better if the underlying data is not accurate.

3

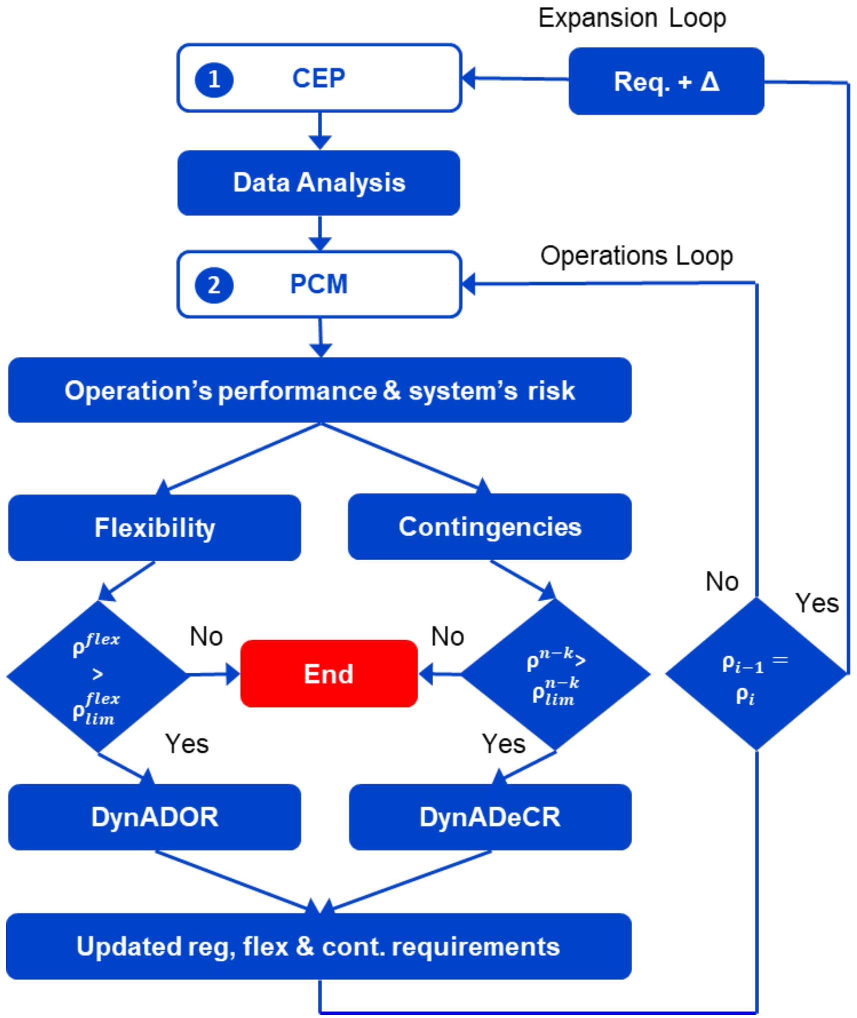
Developing Robust Capacity Expansion Portfolios via Operational Risk Analyses

3

Developing Robust Capacity Expansion Portfolios via Operational Risk Analyses

Objective

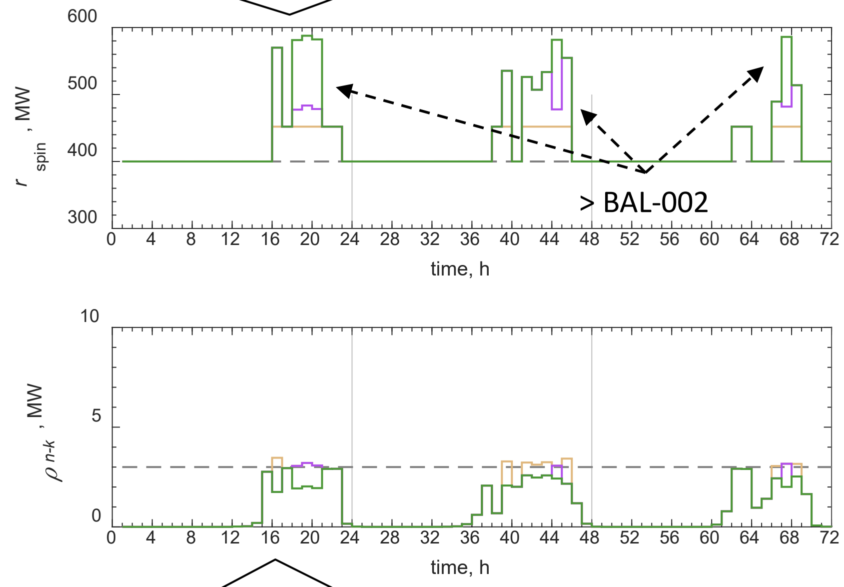
- Capacity expansion plans need to account for increased fidelity as operating conditions become fundamental for system design
  - Flexibility requirements to respond to variability and uncertainty
  - Intertemporal couplings to schedule emerging technologies, such as energy storage
  - System risk exposure to contingent events
- This process requires “closing the loop” between CEP and PCM
  - Need to use a metric to assess system performance for a given expansion plan → risk of insufficient reserves
  - Need a control parameter to mitigate risk → operating reserves



Motivation for Risk Analysis in System Planning

- 8760 hourly simulations such as those in Step 2 are valuable as a “first line of defense” to identify potential violations for proposed system expansion but are not alone sufficient to fully assess system reliability under different potential adverse conditions.
- Critical period selection is fundamental to assess system risk and reliability against credible deviations.
- The difference between system risk and risk tolerance can be used to adjust system operating reserve requirements, to eventually reduce the system risk to tolerable level.
- Operating reserve adjustments occur only in needed periods, in which the system risk is greater than the tolerable level; while the reserves during other periods are maintained.

Contingency reserve requirements as a function of time. The dashed line represents the BAL-002-2

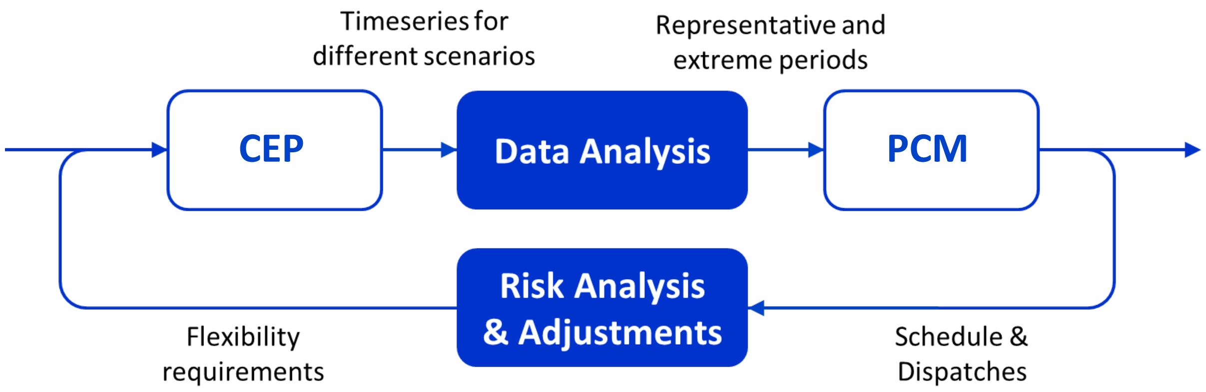


System risk exposure (i.e., expectation of insufficient reserves) as a function of time for each iteration in the loop process, until system risk is equal or below target.

CEP & Production Cost Modeling Linking Process

- Tool agnostic process, which loops any CEP and Production Cost Modeling tools:

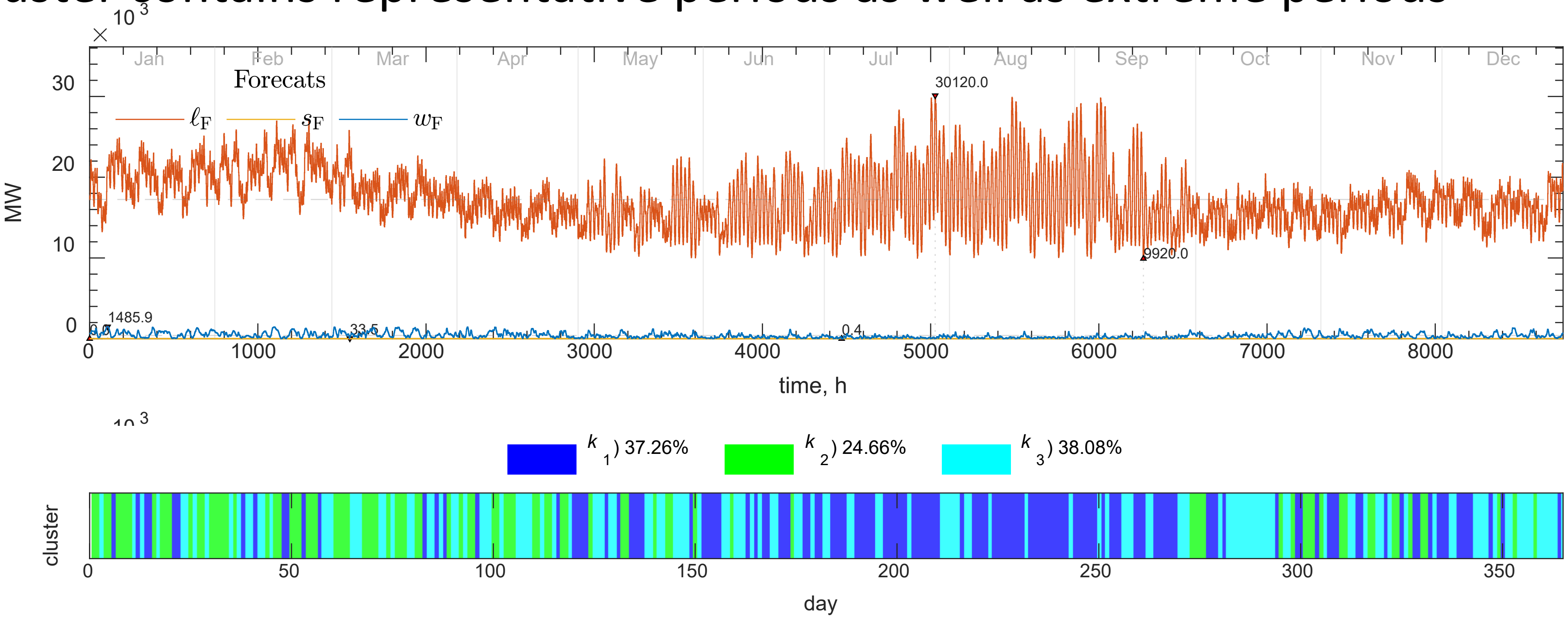
1. Time series (e.g., load, wind, and solar.) data analysis (CEP → PCM):
   - Identification of representative and extreme/critical (e.g., peak, valleys, sustained/steep ramping, etc.)
2. System risk exposure analysis (CEP ← PCM):
   - Assess risk of operating conditions and resources against:
     - Continuous events: Shortage of regulation and flexibility reserves that might result in load violations
     - Discrete events: Shortage of contingency reserve that might result in load balance violations



See also: Program on Technology Innovation: "Coordinated Expansion Planning with Increased Temporal Resolution: Embedding Production Simulation Models," EPRI, Palo Alto, CA, Rep. No. 3002018763, Dec. 2020.

Data Analysis and Clustering

- Using the yearly data, cluster days based on net load profile commonalities
- Clustering does not necessarily lead to seasonal grouping
- Each cluster contains representative periods as well as extreme periods

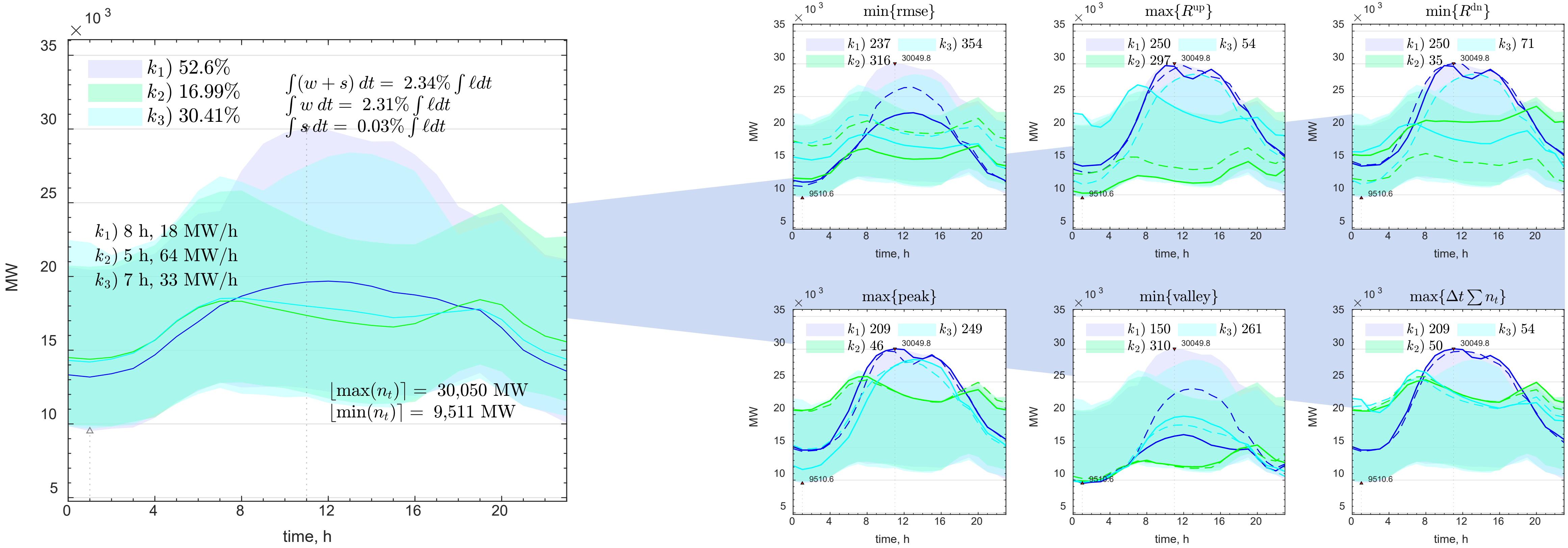


Day clustering. Each color represents a cluster, and the percentages are for number of days in a year.

See also: Program on Technology Innovation: "Coordinated Expansion Planning with Increased Temporal Resolution: Decomposition Solutions," EPRI, Palo Alto, CA, Rep. No. 3002020160, Dec. 2020.

Data Analysis and Cluster Identification

- Identification of representative and extreme periods for PS assessment
- Clusters are generated with respect to a specific feature (e.g., peak, valley, ramp, etc.)



- The element with the largest preferred feature is chosen to represent the cluster

Assessment of Critical Days

- Chosen days can then be assessed in a detailed production simulation tool
- The first production cost modeling steps consisted of performing a reliability check (See Section 2 on “Improving Capacity Expansion Portfolios with Resource Adequacy and Operational Reliability Evaluations”
  - Again, such reliability check might be insufficient, as it only assesses system performance against a single realization of the stochastic variables
- In order to overcome the limitations of the assessment using a single realization of the stochastic variables, the system risk is calculated in two parts:
  - Risk of resources/services shortage against continuous deviations (e.g., variability and uncertainty)*
  - Risk of resources/services shortage against discrete deviations (e.g., contingencies)**
- The next slides present a method to assess the risk exposure of the system against continuous and discrete events

*M. A. Ortega-Vazquez, N. Costilla-Enriquez, E. Ela, A. Tuohy, "Risk-Based Reserve Procurement," 2020 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Liege, Belgium, Aug. 18-21, 2020.

**M. A. Ortega-Vazquez and D. S. Kirschen, "Optimizing the Spinning Reserve Requirements Using a Cost/Benefit Analysis," IEEE Trans. Power Syst., Vol. 22, Issue 1, pp. 24-33, Feb. 2007.

From Operating Planning to Expansion Planning

- Given a generation and transmission portfolio, assess detailed operating planning
- Operating planning should gauge if the existing portfolio is not only adequate, but sufficiently flexible to respond to future net demand variability and uncertainty
- Conventionally, this assessment consists in:
  - Counting the number and magnitude of load and reserve violations
  - If insufficient, larger headroom/footroom requirements were enforced in the EP problem
  - Enhanced variants itemize the headroom/footroom into specific reserve needs (reg., flex, cont.)*
- While practical, using headroom/footroom of a given solution as a proxy for system performance could be myopic
  - Increasing these requirements blinding does not capture the kind of resources needed to meet the desired target (slow cheap base generation, agile peaking generation, storage devices, etc.)
  - Need to identify practical system performance metric that capture components of such information

*Program on Technology Innovation: "Coordinated Expansion Planning with Increased Temporal Resolution: Embedding Production Simulation Models," EPRI, Palo Alto, CA, Rep. No. 3002018763, Dec. 2020.

Inputs/Outputs for Control

- Production Cost Modeling:
  - Generation fleet
  - Transmission network
- Capacity Expansion Planning:
  - Reserve products (regulation, flexibility, contingency)
  - Candidate generation and transmission

- Process:
  1) Run PCM and assess metrics that would re-calibrate reserve requirements, or identify candidates
  2) Enforce reserves and candidates in CEP
  3) Repeat process

Risk as Metric

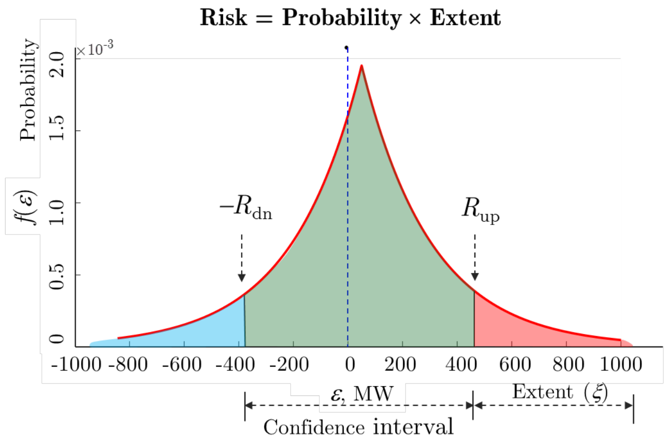
- Risk is, by definition, the expectation of loss:
  - Likelihood of shortage/damage
  - Magnitude of expected shortage/damage

- Risk considers endogenously the ability of the system to respond:
  - Technical aspects of committed fleet (i.e., dispatch, capacity, and ramps)
  - Reliability aspects of committed fleet (i.e., likelihood of forced outages)
  - Flexible systems can accommodate a wide spectrum of deviations in operation
  - Flexible systems are less likely to produce power balance violations after contingencies
  - Constrained systems are likely to produce result in systematic risky operating periods

M. A. Ortega-Vazquez, N. Costilla-Enriquez, E. Ela, A. Tuohy, "Risk-Based Reserve Procurement," 2020 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Liege, Belgium, Aug. 18-21, 2020.
M. A. Ortega-Vazquez and D. S. Kirschen, "Estimating the Spinning Reserve Requirements in Systems with Significant Wind Power Generation Penetration," IEEE Trans. Power Syst., Vol. 24, Issue 1, pp. 114-124, Feb. 2009.

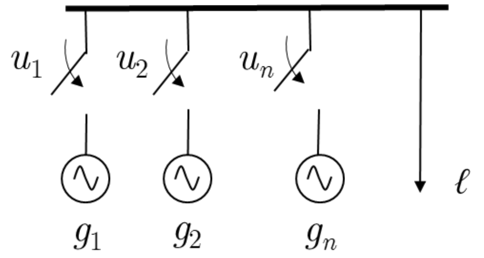
Risk as Metric for Reserve Procurement

- Flexibility reserve requirements:
  - Considers likelihood and extent of potential deviations
  - Accounts for the distribution of deviations over the period of interest
  - If either forecasts and/or actuals are unavailable, the distributions can be constructed, and reserves could still be estimated



- Contingency reserve requirements:
  - Considers likelihood and extent of potential deviations
  - Considers generation fleet explicitly (i.e., capacities, ramp rates, activation time, and failure rates)
  - Considers operating point (by-product of UC/ED)
  - Captures the inherent flexibility of the online resources

$$\sum_i r_i \geq f(n-k)$$



M. A. Ortega-Vazquez, N. Costilla-Enriquez, E. Ela, A. Tuohy, "Risk-Based Reserve Procurement," 2020 International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), Liege, Belgium, Aug. 18-21, 2020.
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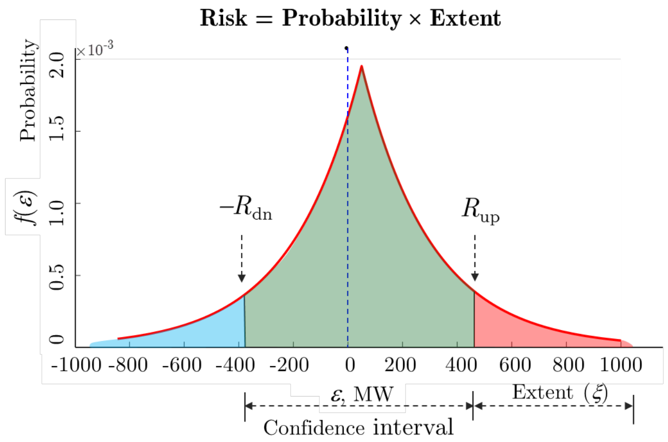
Choosing the Risk Limit for Flexibility (ρ^{flex})

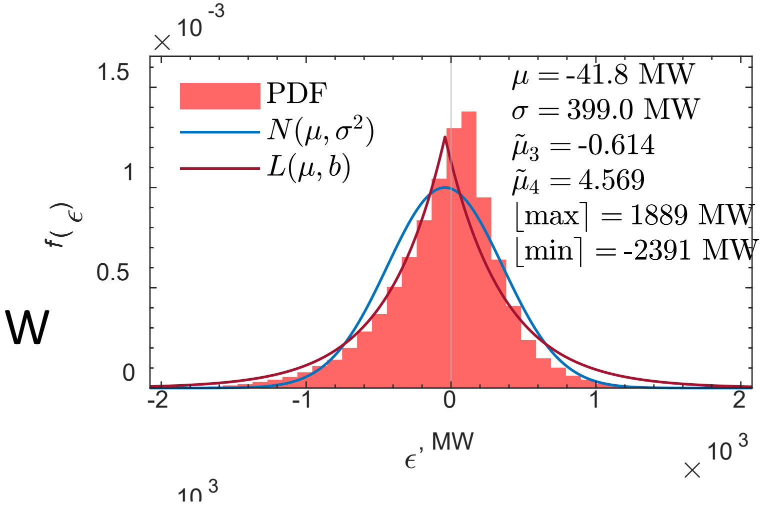
- The distribution of deviations is non-parametric
- Such distribution is built from historical datasets of forecasts and actuals
- A **rule-of-thumb** to have ***an idea of the magnitude*** of the risk limit, it is useful to look at the tails of the distribution:
  - Assuming symmetry the tails are of about 1300 MW
  - If we assume a CI of 90%, that is 5% not covered on each tail
  - The associated probability is:

$$p_x = \int_{1300}^{x} f(\varepsilon)\, d\varepsilon = 0.05$$

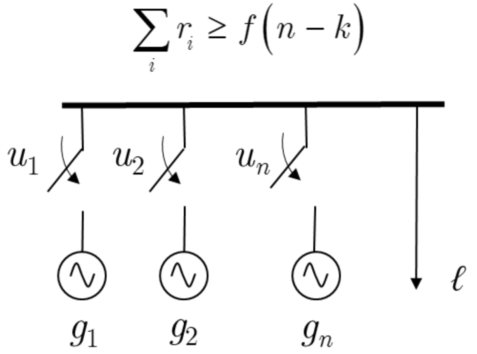
  - The tails are long and of low probability, therefore a value of 200 MW would be a reasonable guess for *x*

$$\rho^{flex}_{\text{limit}} \square \left(200 \times 0.05\right) = 10\ \text{MW}\Delta t$$





Choosing the Risk Limit for Contingencies ($\rho_{n\text{-}k}$)



- Risk assessment is a complex multifactorial process
- Deterministic reserve requirements rules-of-thumb are practical and simple to understand, but are not risk measures
- Need a simple process to translate reserve rules-of-thumb to meaningful risk ceilings
- The ***ballpark risk ceiling*** can be estimated as:

$$\rho_{\text{limit}}^{n-k} \square \left(\overline{ORR} \times (\text{Spin. Req.})\right) = 137.4\ \text{MW}\Delta t$$

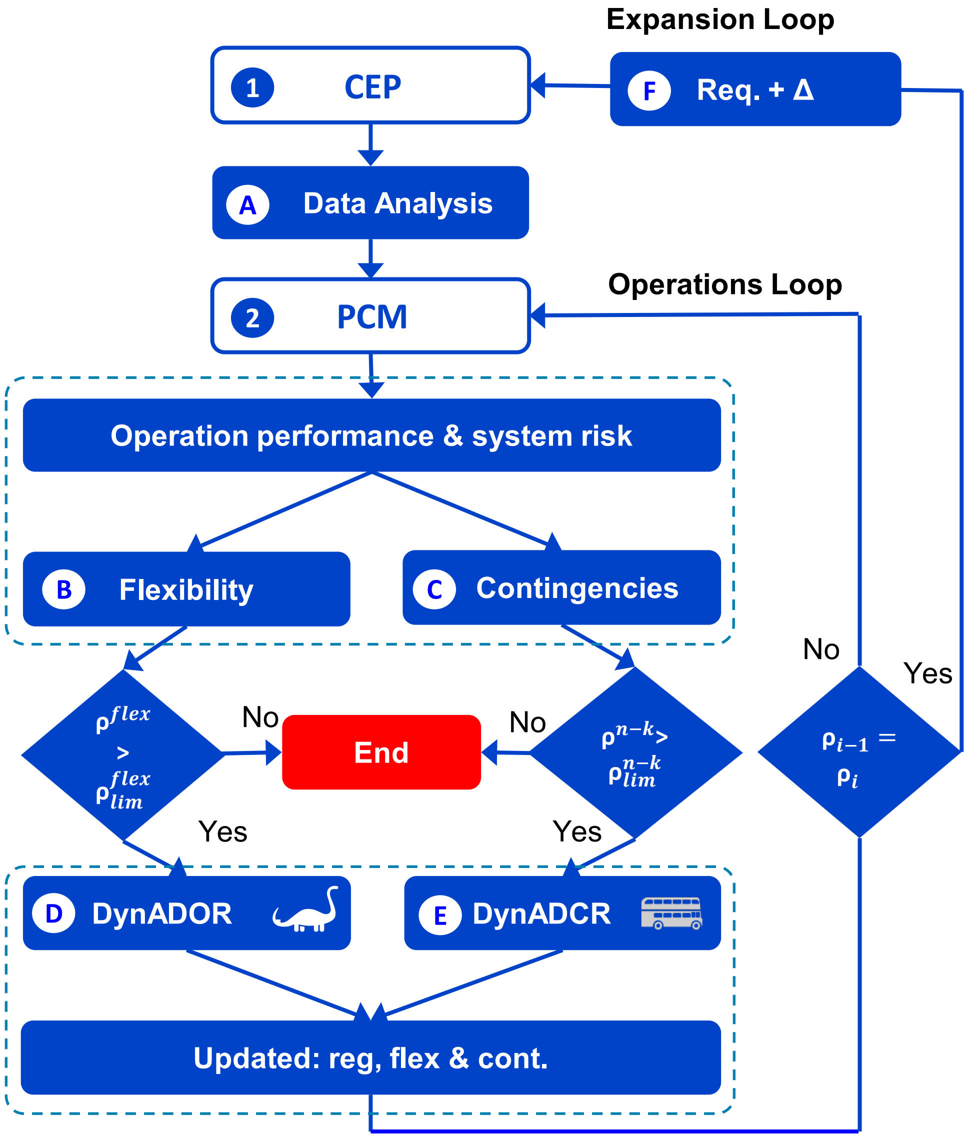
Average outage rate of all units

N-1 criterion or other (e.g., 1.5×(N-1))

To be understood as losing 1.5×1298.7 MW with a probability of 0.068979 in the 2015 NYISO System

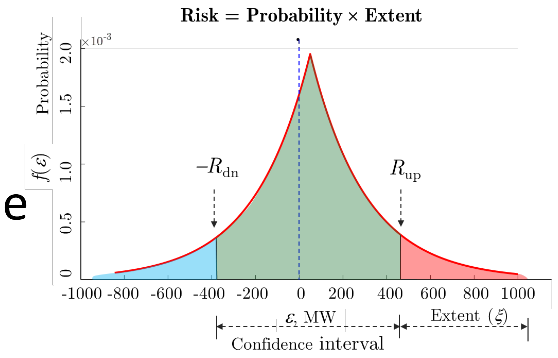
Linking Flow Diagram

- PCM solution assessed for:
  - Power balance violations
  - Reserve requirements violations
  - UC and ED constraints violations
  - Risk against continuous and discrete events
- If risk is greater than limit:
  - Risk-based flex. reserve req. computed using DynADOR
  - Risk-based cont. reserve req. computed using DynADCR
  - Recalculate PS with new requirements and check risk
  - If risk is limit is not met, enforce requirements in CEP
- If risk is equal or lower than limit
  - Maintain reserve requirements

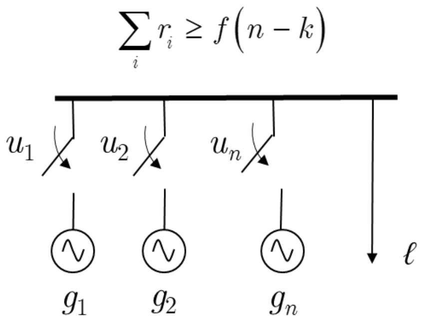


Flow Diagram Components

- B) Flexibility: Operations’ performance & system risk
  - This step assesses the performance of the system against a pre-defined distribution of deviations
  - Such distribution of deviations can be obtained from historical data sets (if the portfolio of VRES has not changed) or predicted based on physical quantities such as wind speed and solar irradiance from databases*,**



- C) Contingencies: Operations’ performance & system risk
  - This step assesses the system’s risk exposure against contingencies
  - The distribution of the deviations is built from the availabilities of the synchronized resources. This distribution is combined with the net load to serve to estimate the expectation of being short of contingency reserves to maintain the system power balance



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*NREL, “Wind Resource Data, Tools, and Maps,” 2021. [Online]. Available: https://www.nrel.gov/gis/wind.html
**NREL, “NSRDB: National Solar Radiation Database,” 2021. [Online]. Available: https://nsrdb.nrel.gov/

Flow Diagram Components

- If the system risk from B and/or C is larger than limit, then the reserve requirements are adjusted to attain a risk equal or lower than the limit
- D) DynADOR (Dynamic Assessment and Determination of Operating Reserves)*
  - DynADOR is used to determine the dynamic flexibility reserves needed to maintain the risk at or below the enforced limit
- E) DynADCR (Dynamic Assessment and Determination of Contingency Reserves)
  - DynADCR is used to determine the contingency reserves requirements to maintain the system risk at or below the desired limit
- F) In D and E it is possible that the requirements cannot be met with the available resources, and thus there would generate reserve violations and system risk would not change. In this case, it is required to update the reserve requirements and re-run the expansion planning model again, to generate a different portfolio of resources

*EPRI, “Dynamic Reserve Determination Tool,” 2020. [Online]. Available: https://www.epri.com/research/products/000000003002020168

Contingency Reliability Standards & System Risk

- Contingency reliability standards determine a minimum amount of reserve that should be carried in a system to guarantee a desired outcome
- For instance, from the NERC BAL-002-2 disturbance control standard the minimum amount of contingency reserve is such that the system must be able to withstand the most severe single contingency*
  - This standard disregards the likelihood of undergoing the most severe single contingency. In a reliable system such probability might be low
  - This standard does not guarantee a similar positive outcome for double or higher order contingencies, which might not be negligible in unreliable systems
- Risk, as a metric accounts for both, likelihood and magnitude of the contingencies
- In order to comply with both, reliability standards and risk limits, the reserve in a system can be set as:

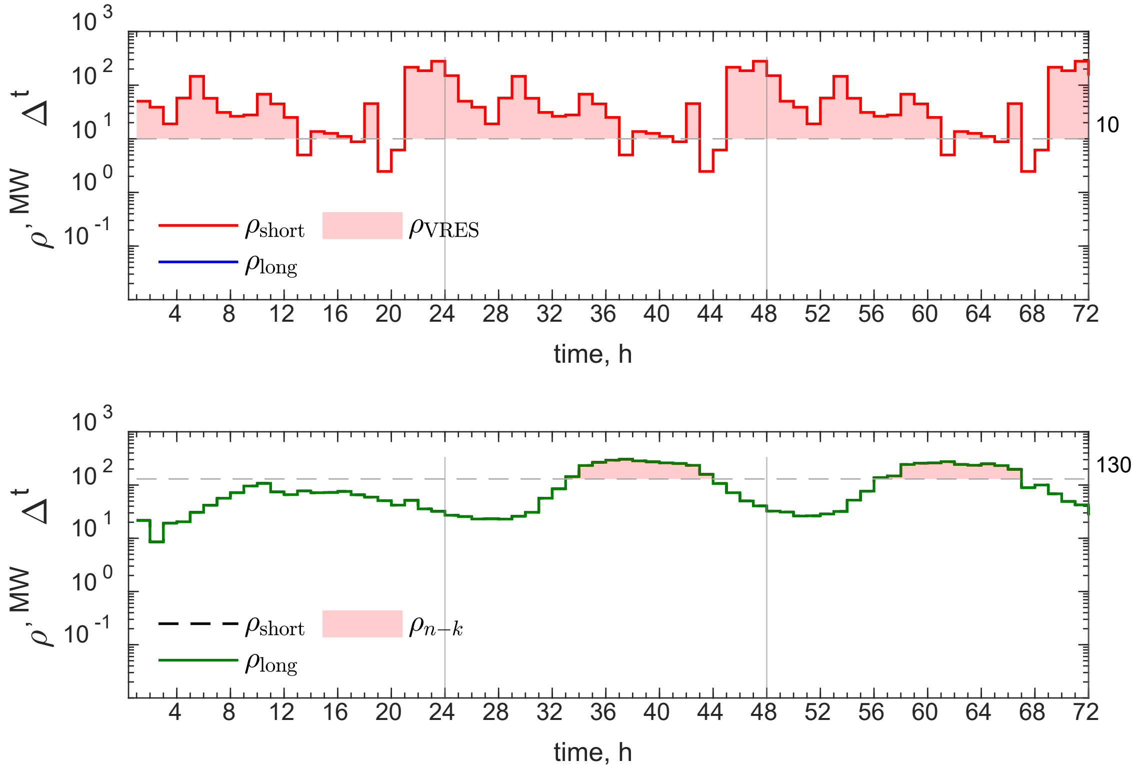
$$r_t = \max\left\{\text{Reliability Standard, Risk-based requirement}\right\}$$

---

*BAL-002-2 – Disturbance Control Standard – Contingency Reserve for Recovery from a Balancing Contingency Event, North American Electric Reliability Corporation (NERC), Atlanta, GA, 2015. Available: https://www.nerc.com/files/BAL-002-2.pdf.

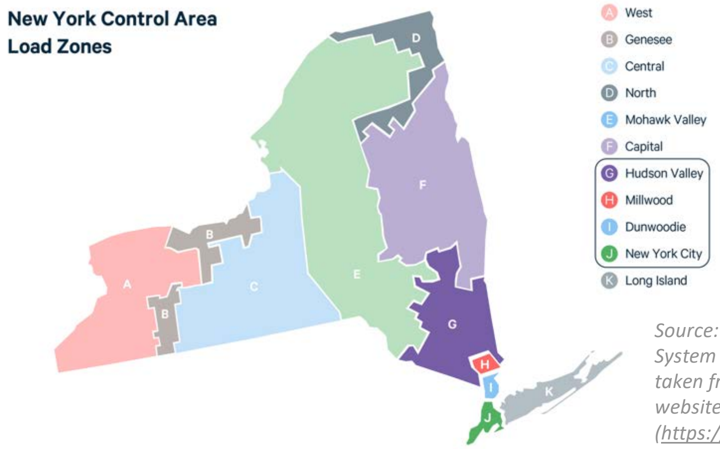
Setting Up Risk Limits

- The best approach is to run the production cost model for the base flexibility and contingency requirements, and measure risk for those values
- Then, adjust accordingly

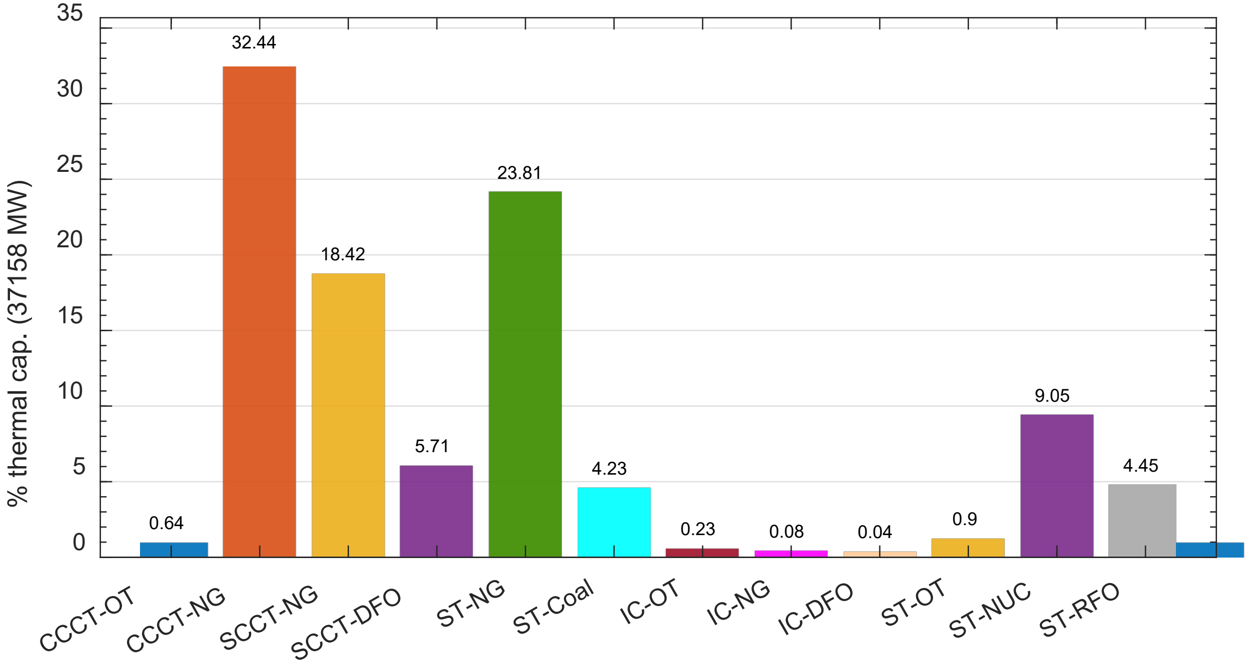


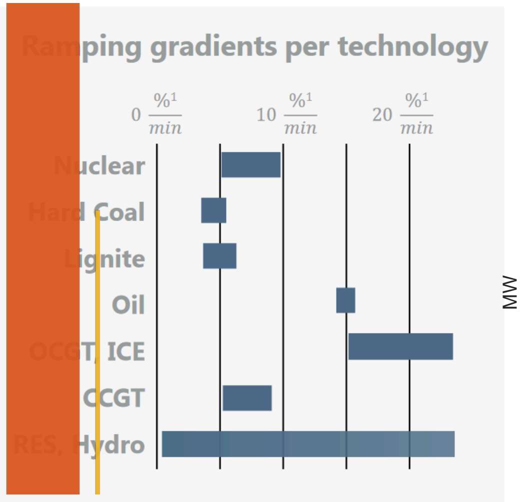
NYISO System, Reference, Year 2035

- Data from US-REGEN & PLEXOS-LT
- Load = [9,670 29,470] MW
- Total thermal capacity 37,158 MW
- Total hydro production 5,816.9 MW



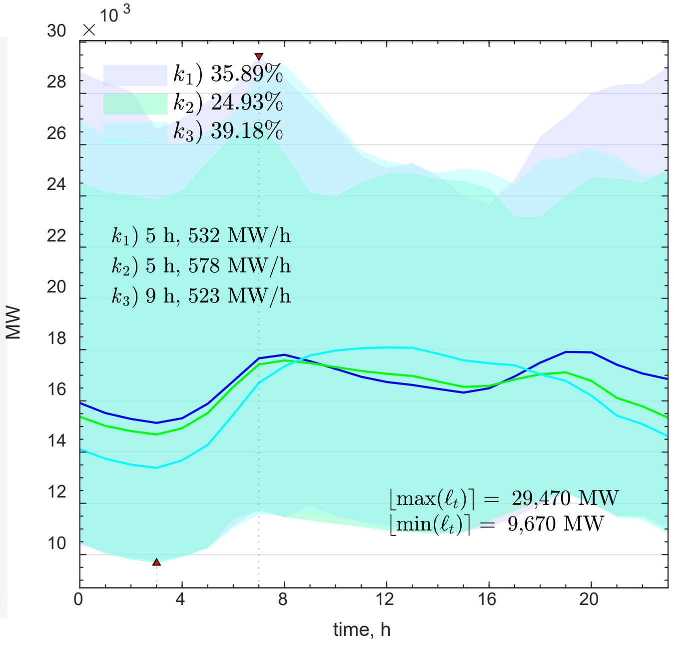
Source: New York Independent System Operator, NYISO map Image taken from Resource for the Future website, n.d. (https://www.resources.org/common-resources/buyer-side-mitigation-nyiso-another-mopr/) with permission.





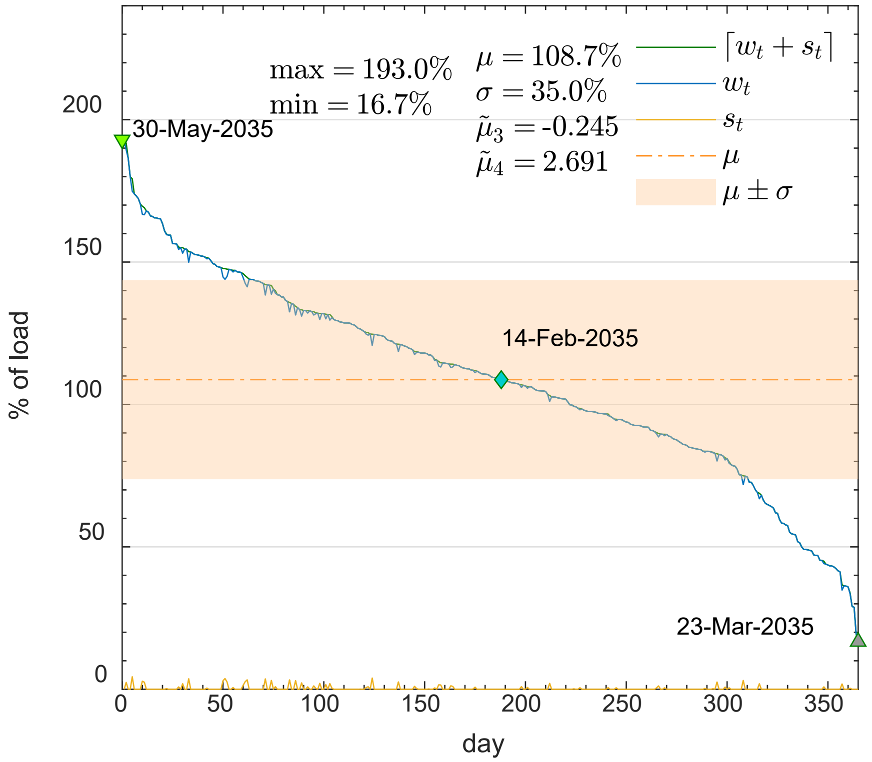
OCGT: Open Cycle Gas Turbine
ICE: Internal Combustion Engines
CCGT: Combined Cycle Gas Turbine

$^1 \frac{\%}{min}$ referred to $P_{\max}$

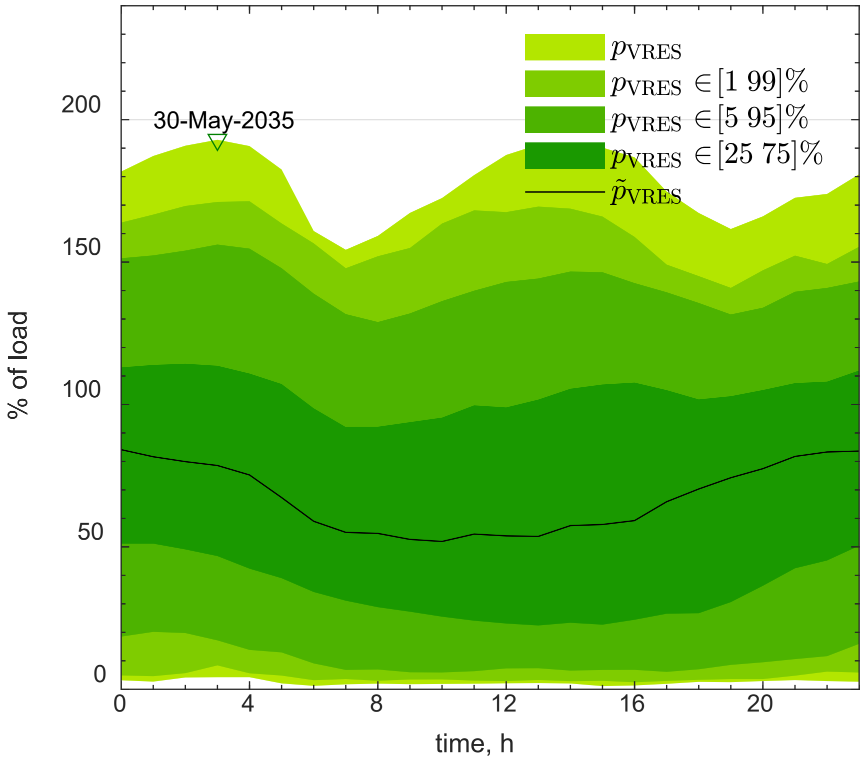


Reference Scenario: Variable Renewable Energy Sources (VRES)

- Installed capacity for wind: 23,167 MW
- Installed capacity for solar: 599 MW



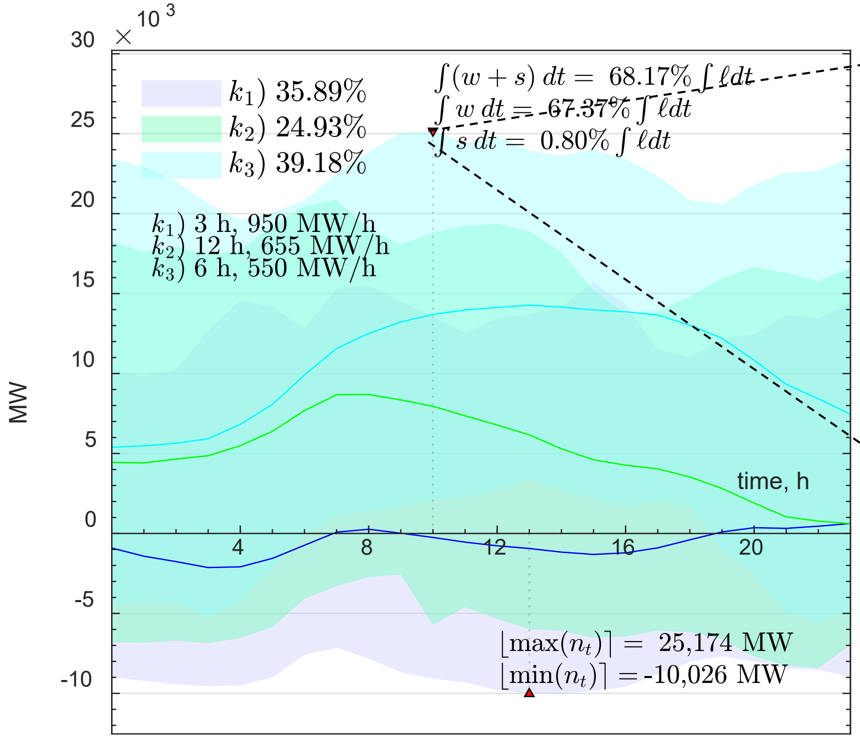
Peak VRES production as percentage of load for each day of the horizon



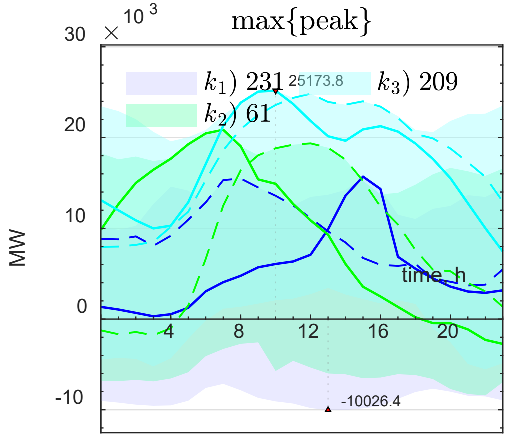
Instantaneous probability density of VRES production in the horizon

Reference Scenario: Selection of Horizon of Study

- Peak net load day chosen for testing 209, (07/29/2035).
  - Omitting hydro generation, since it is constant



Net demand clustering of the time series, and percentage of days in each cluster.



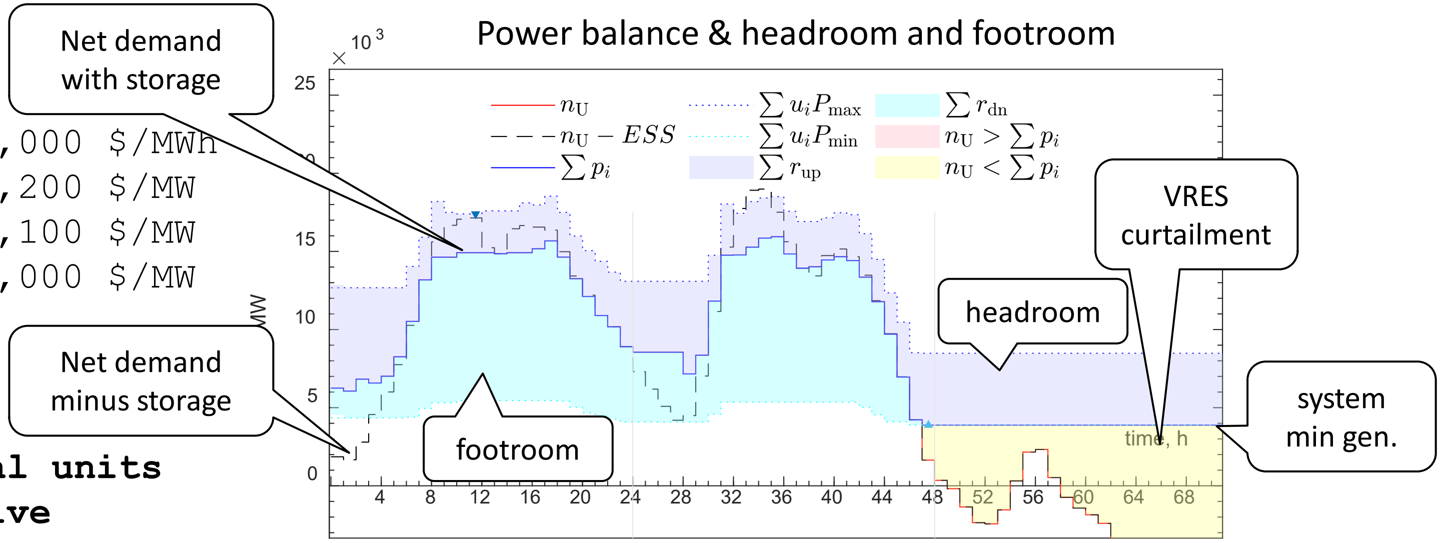
Identification of peak periods in each cluster.

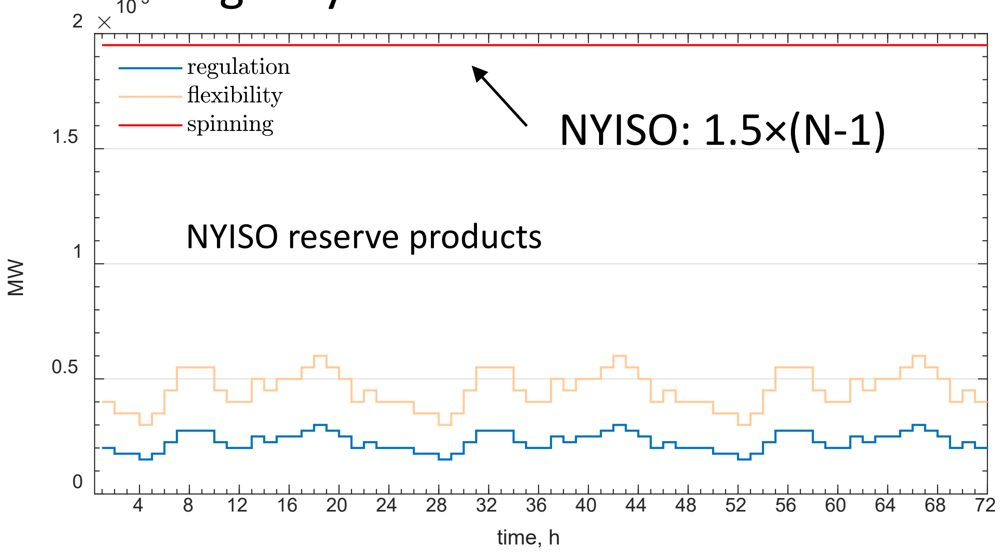
Reference Scenario: Operation Analysis

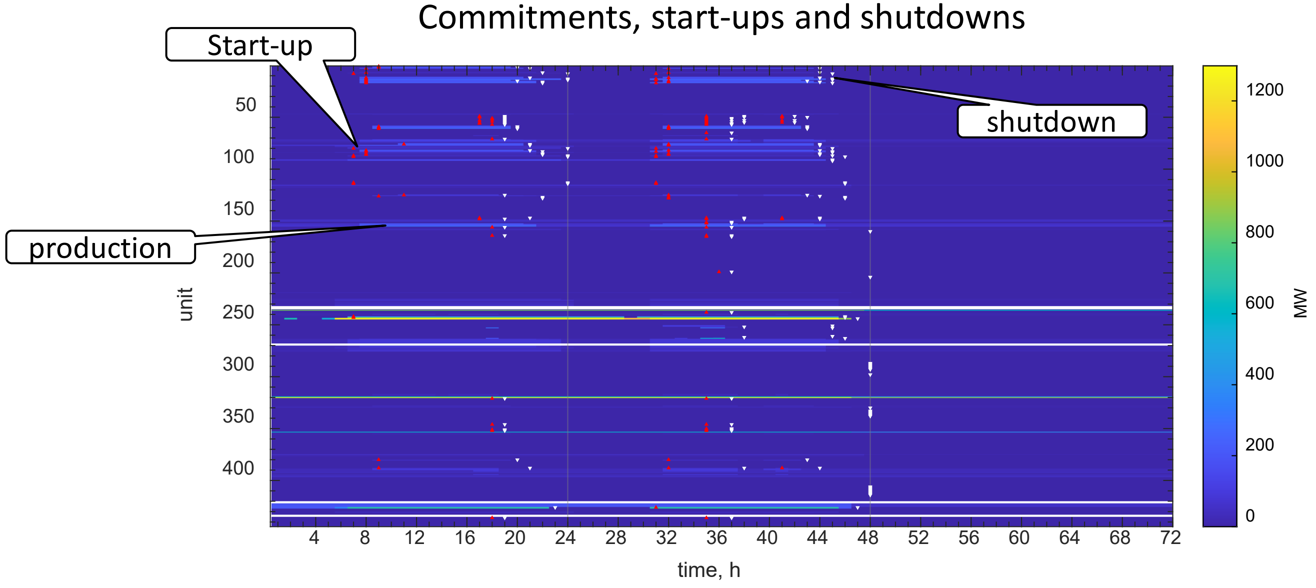
- Scheduling and dispatch:
  - Regulation*
  - Flexibility
  - Spinning (N-1 = 1298.7 MW)
- Risk
  - Flexibility: 10 MWh
  - Contingency: 130 MWh

```
VoLL  = 15,000 $/MWh
PRegu = 13,200 $/MW
Pflex = 13,100 $/MW
PSpin = 13,000 $/MW
```

```
444 total units
339 Active
  5 Retired
```


Power balance & headroom and footroom


NYISO reserve products

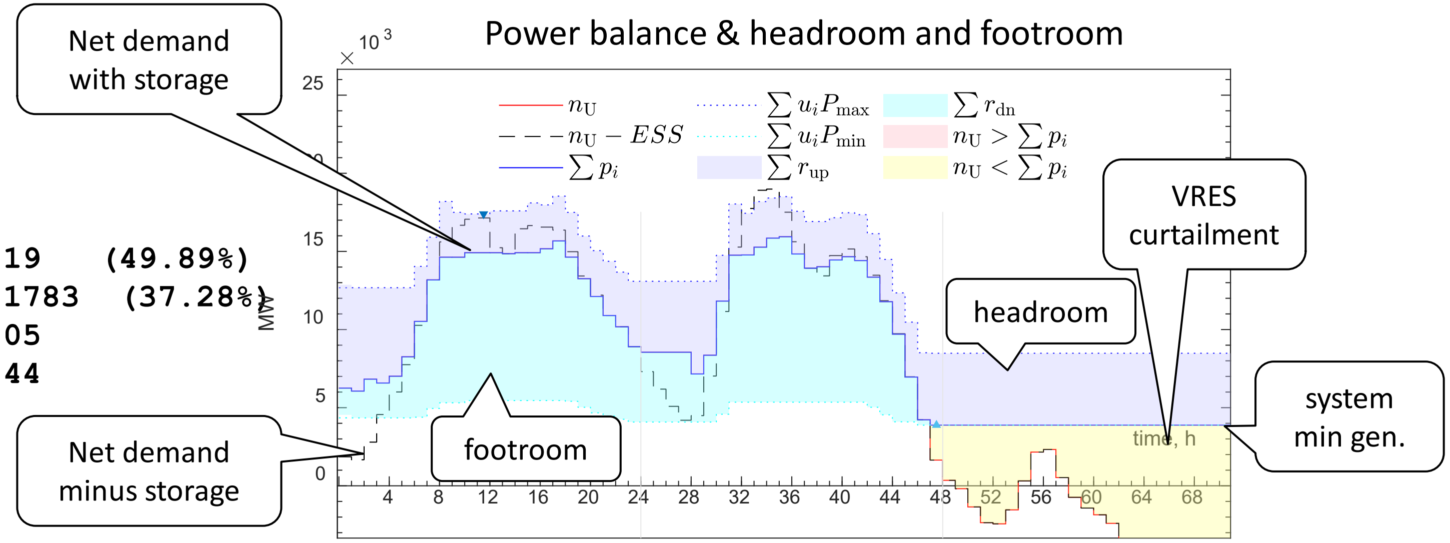

Commitments, start-ups and shutdowns

*https://www.nyiso.com/documents/20142/3694424/nyiso_regulation_req.pdf/6efc0df8-edc2-41bc-9e39-5fed576ba7bc

Reference Scenario: Units’ Utilization

```
OF              10,685,226.07_d
C_generation    8,446,898.42_d
C_no_load       2,135,958.48_d
C_SU            102,369.16_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       0.0000_d
C_SUPP_vi       0.0000_d
```

```
- Units used:   219    (49.89%)
- Commitments:  11783   (37.28%)
- Start-ups:    105
- Shut-downs:   144
```


Power balance & headroom and footroom

Net demand with storage

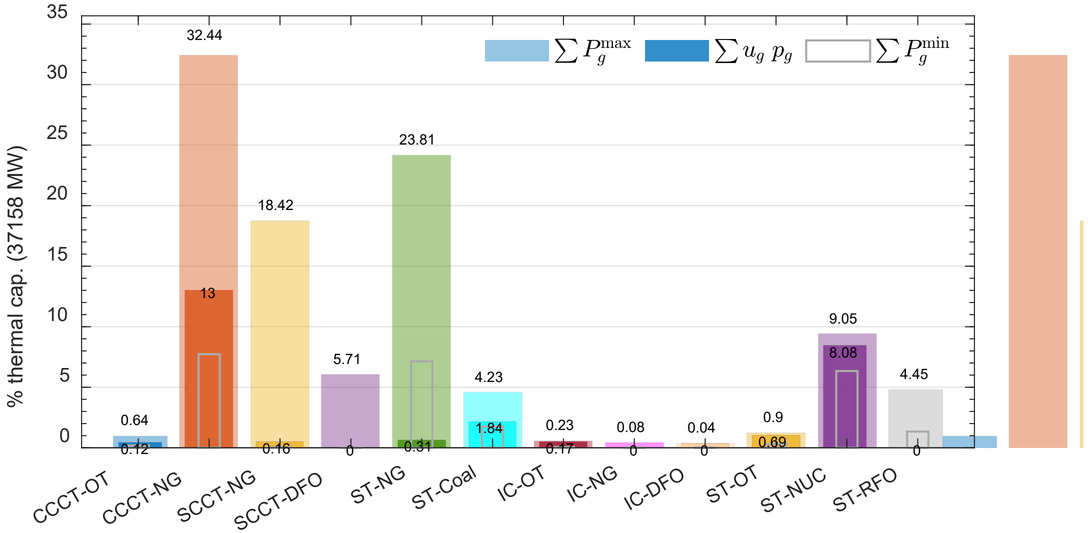
Net demand minus storage

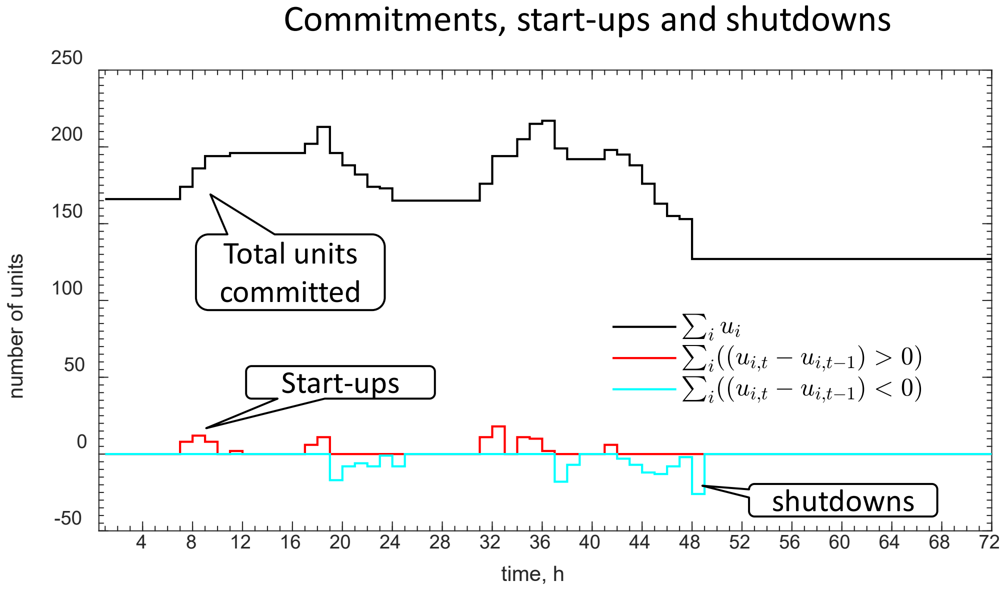
footroom

headroom

VRES curtailment

system min gen.




Commitments, start-ups and shutdowns

Total units committed

Start-ups

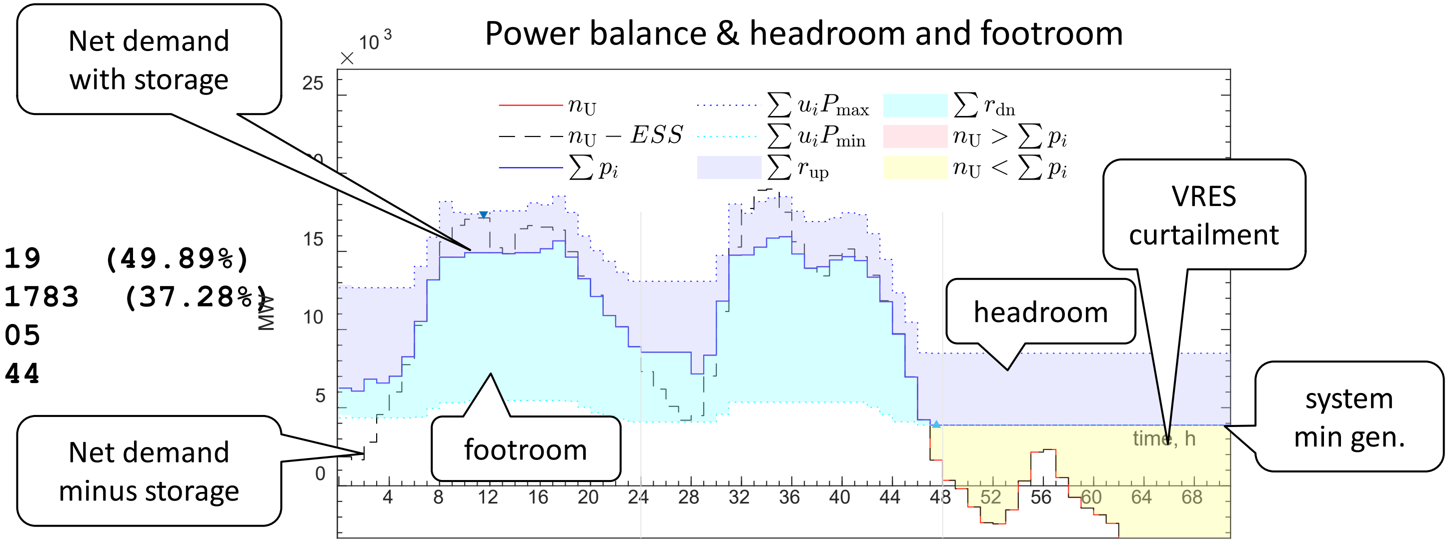
shutdowns

Reference Scenario: Units & Storage

```
OF              10,685,226.07_d
C_generation    8,446,898.42_d
C_no_load       2,135,958.48_d
C_SU            102,369.16_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       0.0000_d
C_SUPP_vi       0.0000_d
```

```
- Units used:   219    (49.89%)
- Commitments: 11783   (37.28%)
- Start-ups:    105
- Shut-downs:   144
```

```
Storage with A/S
18 units:
      4,000 MW
     15,338 MWh
```


Power balance & headroom and footroom

Net demand with storage

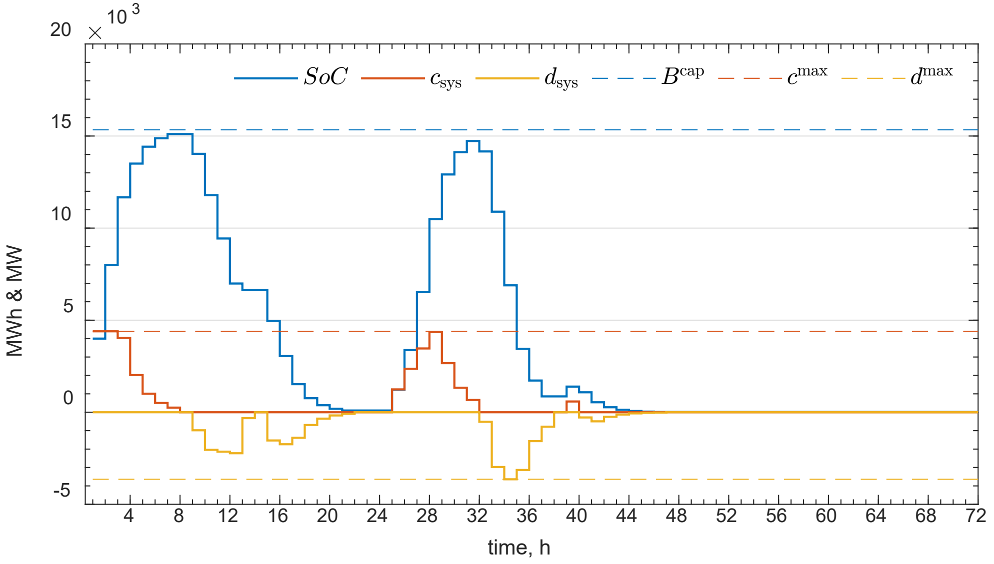
Net demand minus storage

footroom

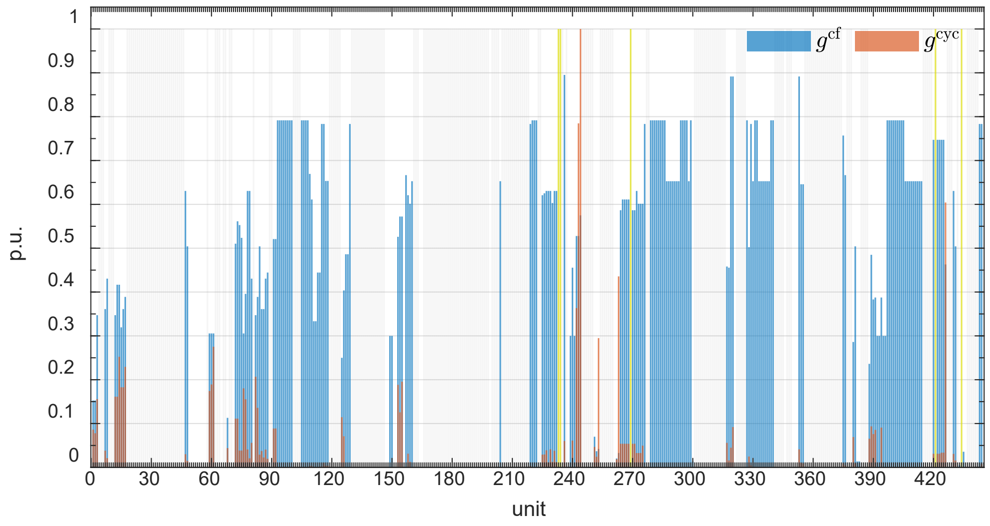
headroom

VRES curtailment

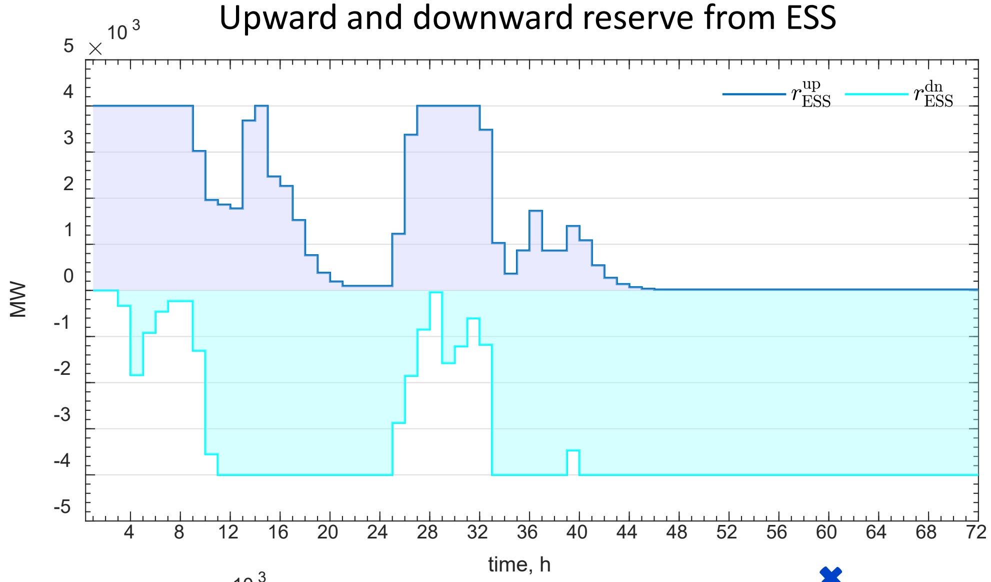
system min gen.



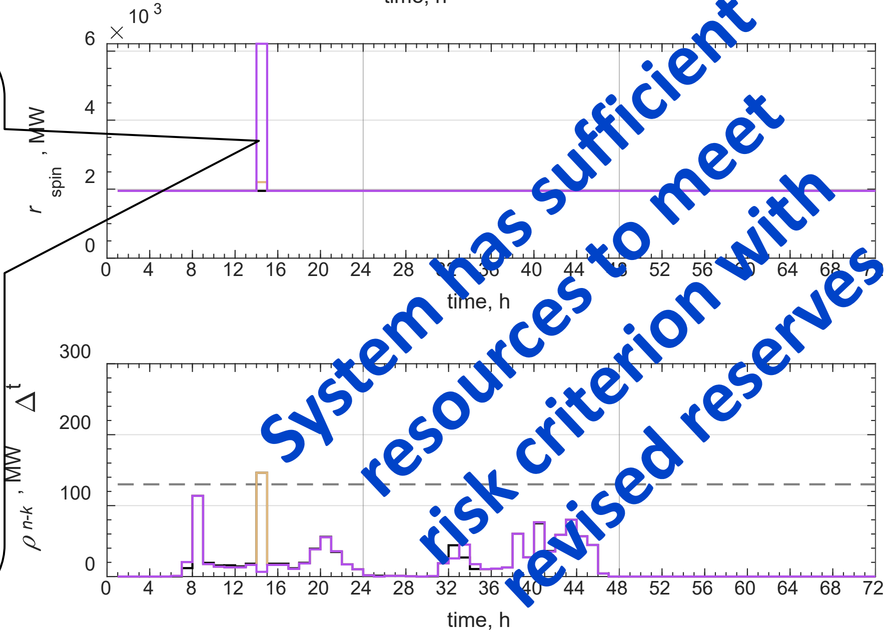
Units' capacity and cycling factors



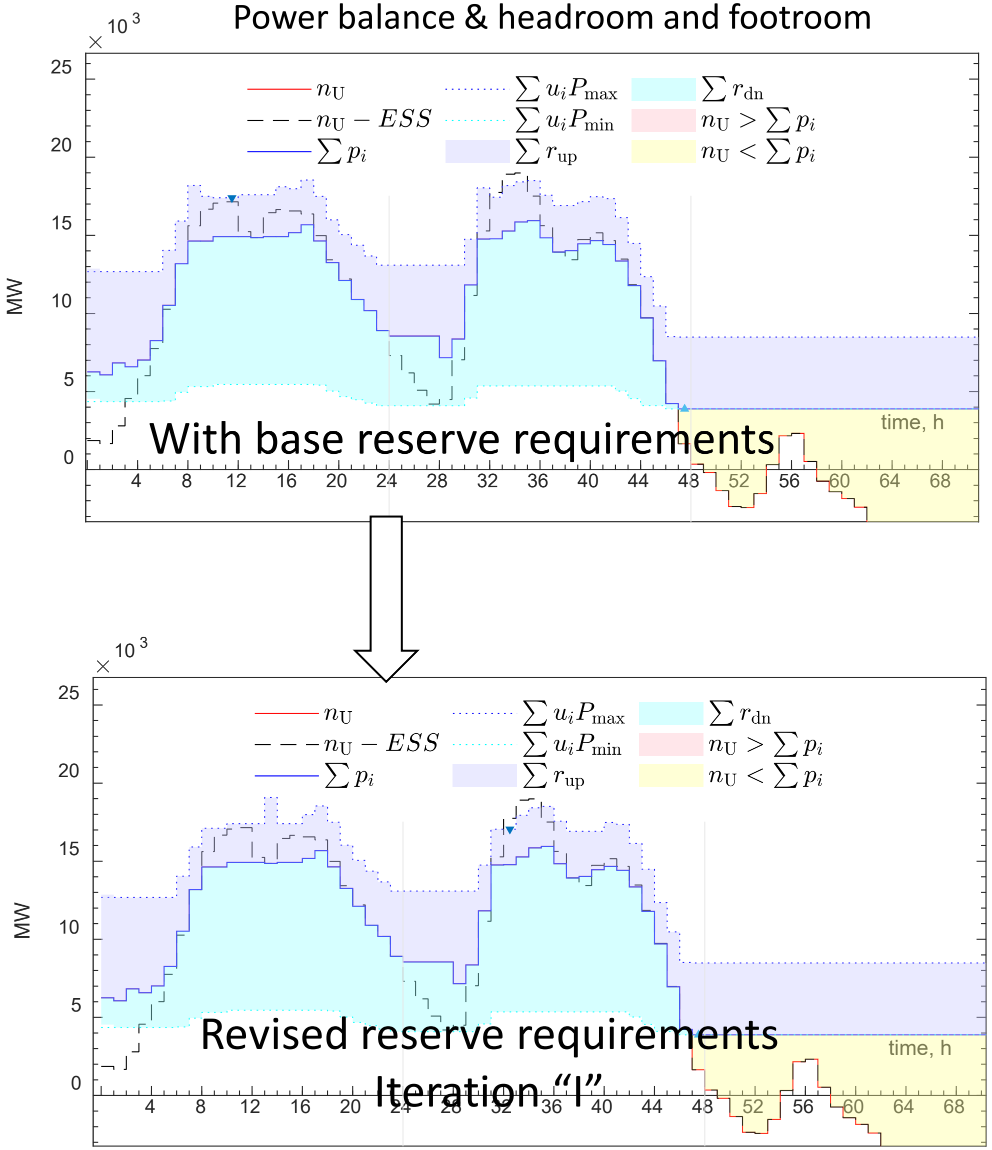
Reference Scenario: Risk Compliance


Upward and downward reserve from ESS

The large peak in reserve requirements, despite a low risk violation, is because the storage unit is large, and it provides up reserve at that period. Therefore, a large requirement is needed to promote the commitment of more generation.



System has sufficient resources to meet risk criterion with revised reserves

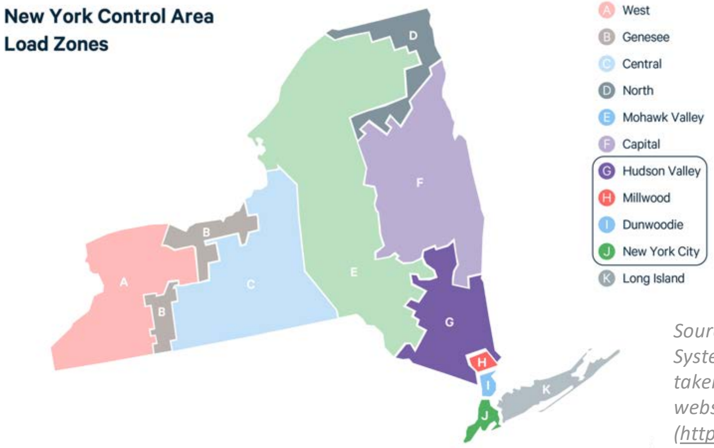

Power balance & headroom and footroom

With base reserve requirements

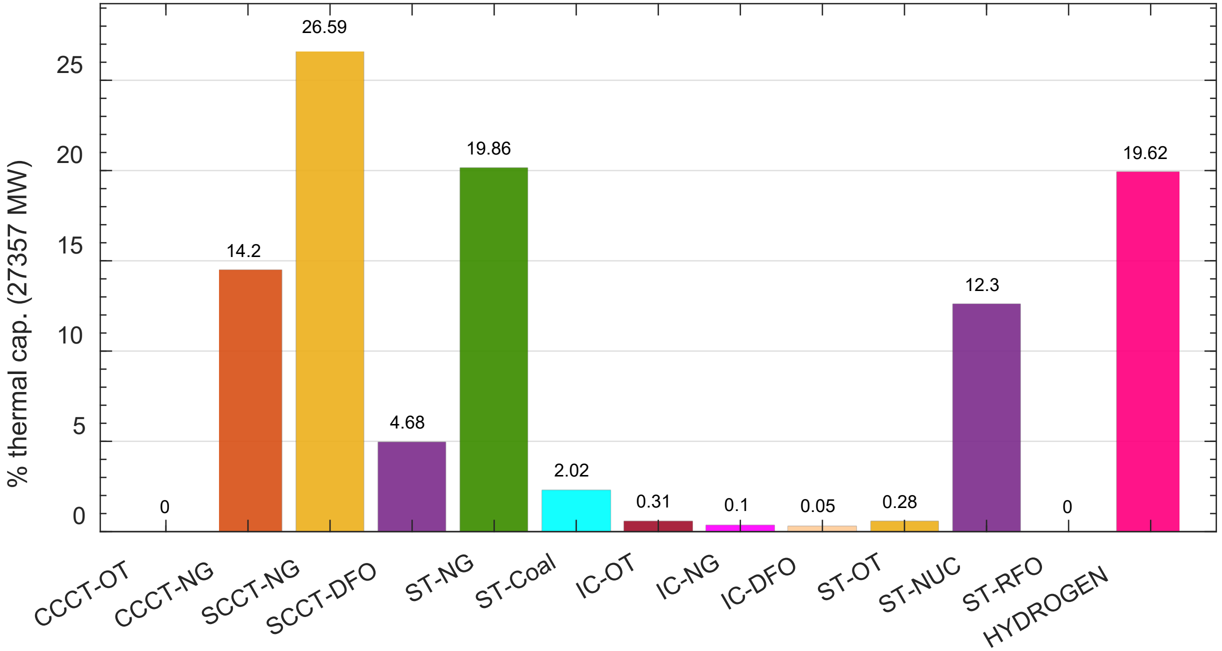
Revised reserve requirements Iteration “I”

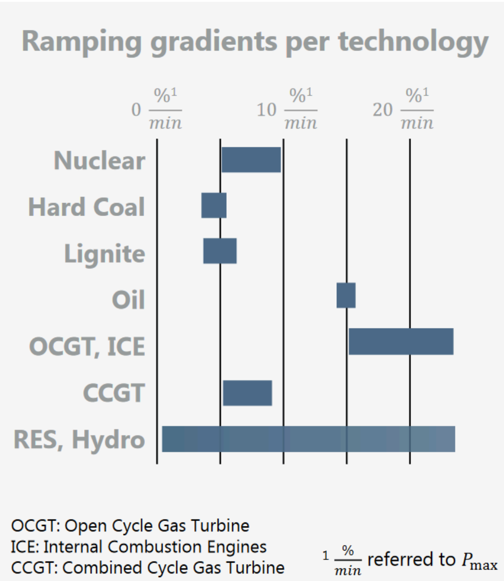
NYISO System, Decarbonization, Year 2035

- Data from US-REGEN & PLEXOS-LT
- Load = [11,270 33,070] MW
- Total thermal capacity 27,357 MW
- Total hydro production 5,816.9 MW



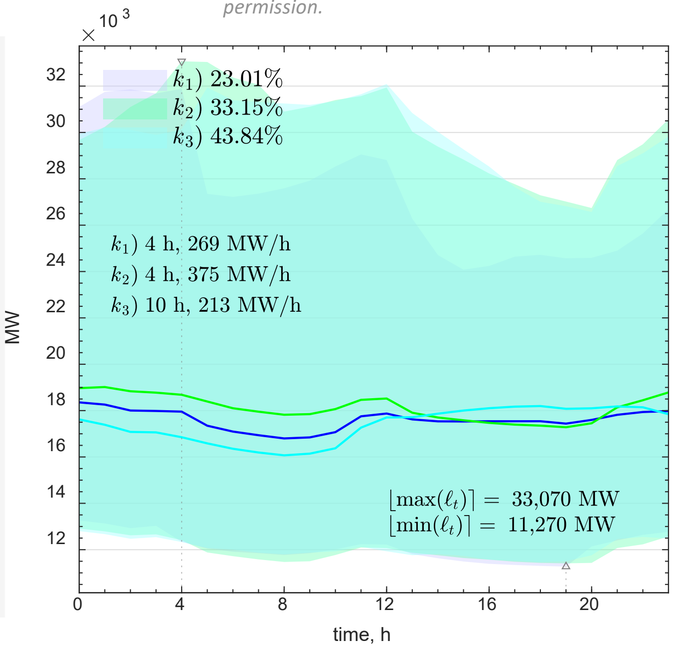
Source: New York Independent System Operator, NYISO map Image taken from Resource for the Future website, n.d. (https://www.resources.org/common-resources/buyer-side-mitigation-nyiso-another-mopr/) with permission.





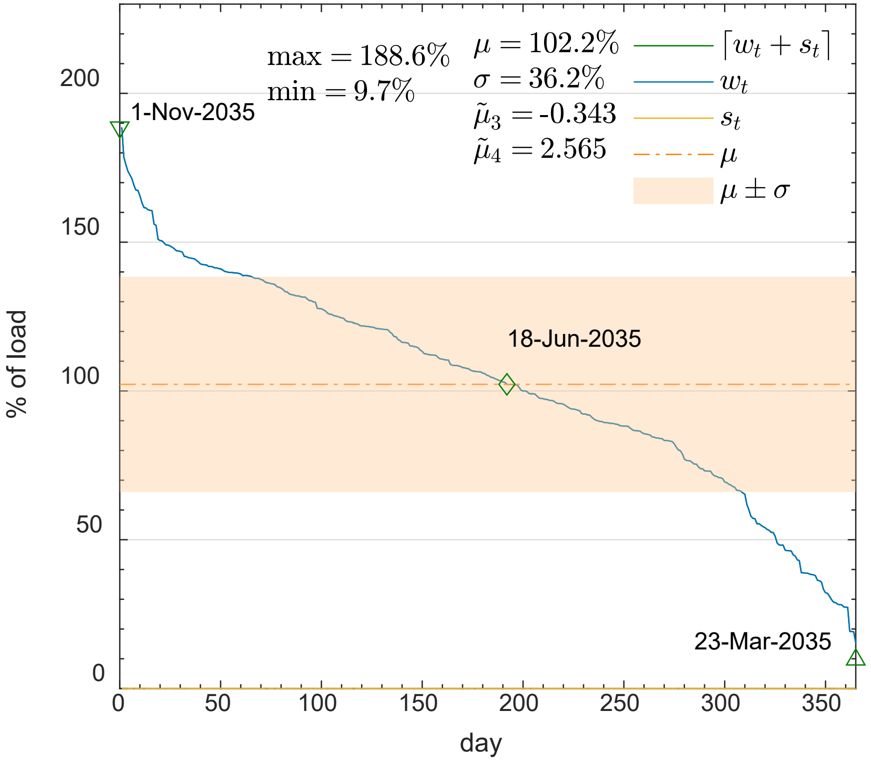
OCGT: Open Cycle Gas Turbine
ICE: Internal Combustion Engines
CCGT: Combined Cycle Gas Turbine

$^1 \frac{\%}{min}$ referred to $P_{\max}$

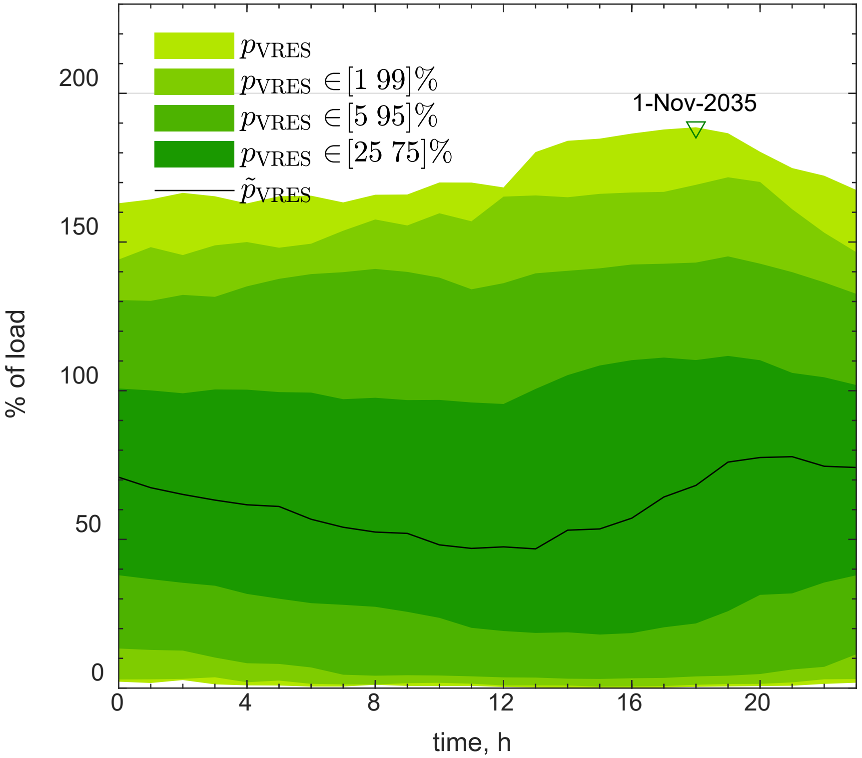


Decarbonization Scenario: Variable Renewable Energy Sources

- Wind: 1,749 + 24,356 = 26,105 MW
- Solar: 227.9 MW



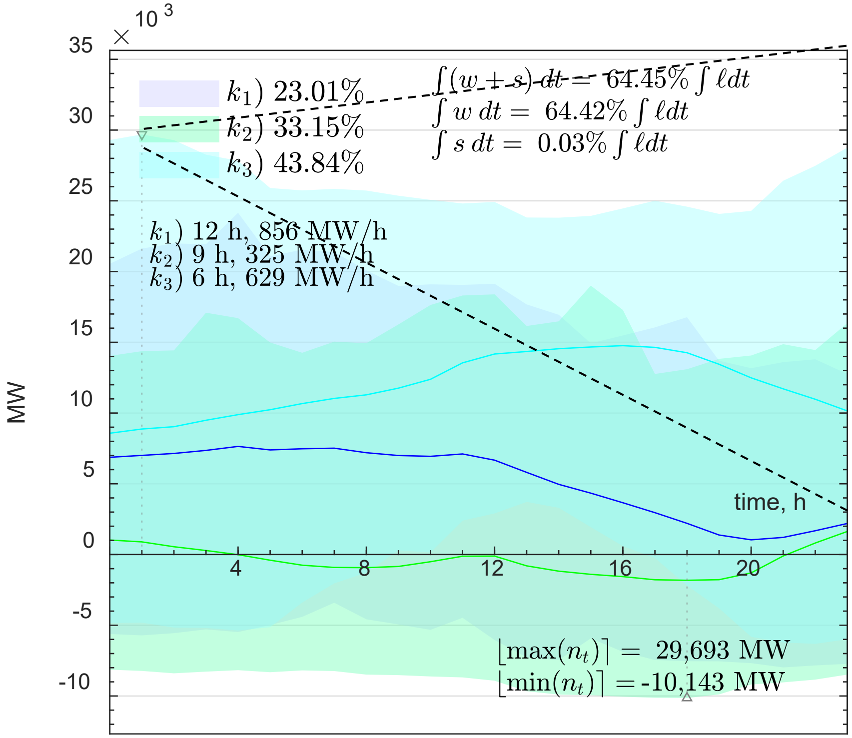
Peak VRES production as percentage of load for each day of the horizon



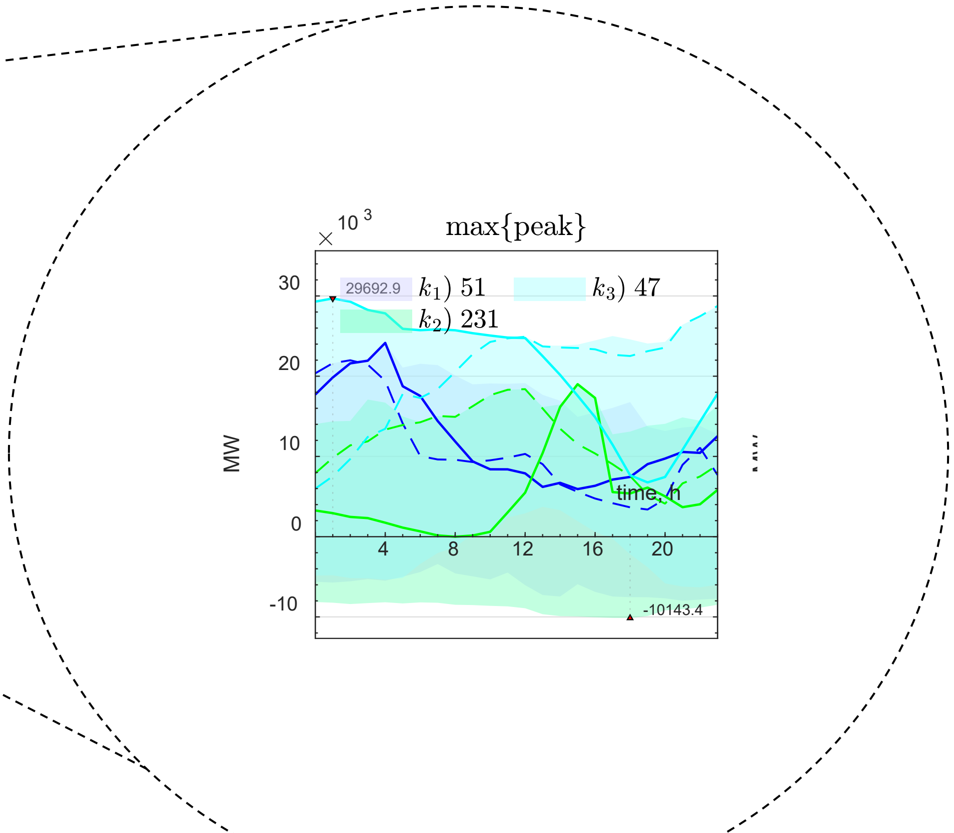
Instantaneous probability density of VRES production in the horizon

Decarbonization Scenario: Selection of Horizon of Study

- Peak net load day chosen for testing 47, (02/17/2035).
  - Omitting hydro generation, since it is constant



Net demand clustering of the time series, and percentage of days in each cluster.



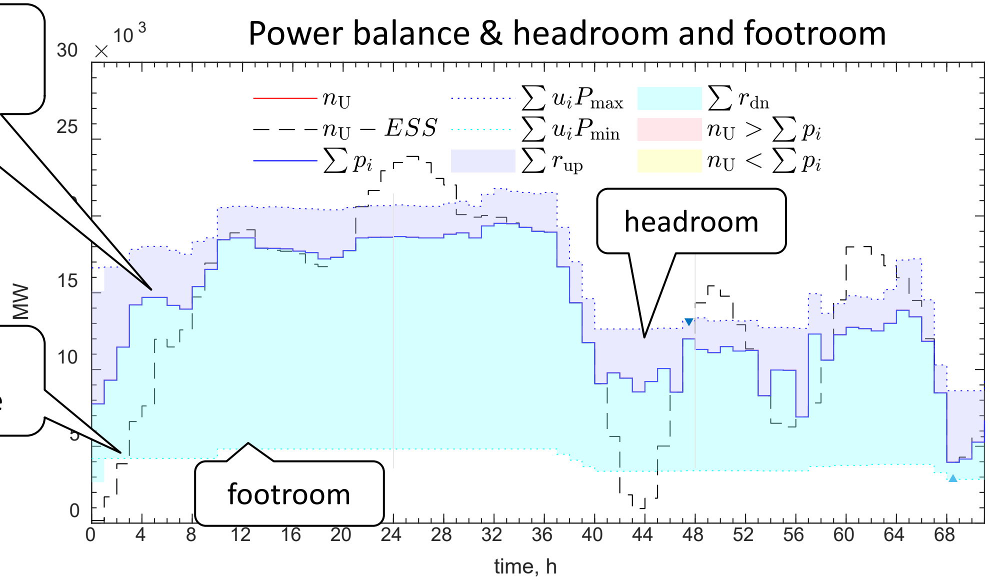
Identification of peak periods in each cluster.

Decarbonization Scenario: Operation Analysis

- Scheduling and dispatch:
  - Regulation*
  - Flexibility
  - Spinning (N-1 = 1298.7 MW)
- Risk
  - Flexibility: 10 MWh
  - Contingency: 130 MWh

```
VoLL  = 15,000 $/MW
PRegu = 13,200 $/MW
Pflex = 13,100 $/MW
PSpin = 13,000 $/MW
```

455 total units
336 Active
119 Retired

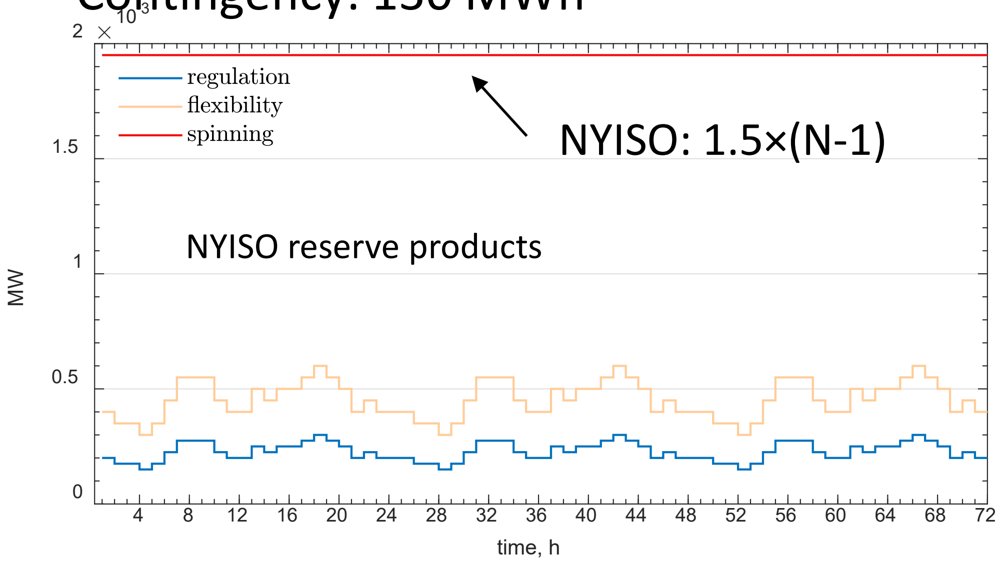

Power balance & headroom and footroom

Net demand with storage

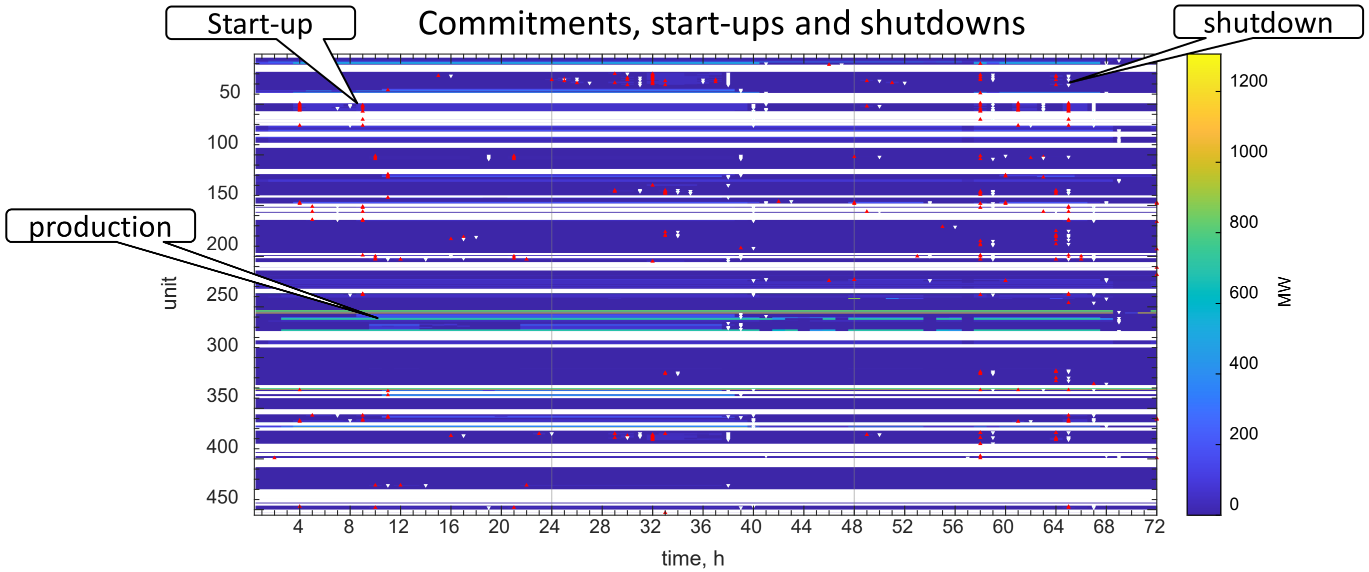
Net demand minus storage

headroom

footroom


NYISO reserve products

NYISO: 1.5×(N-1)


Commitments, start-ups and shutdowns

Start-up

shutdown

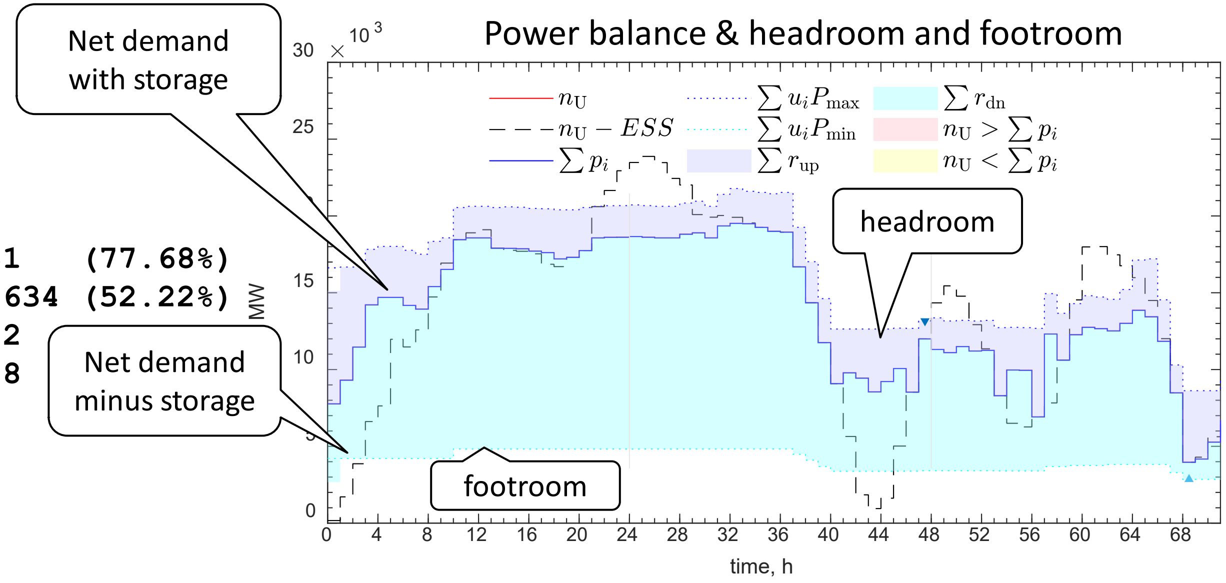
production

*https://www.nyiso.com/documents/20142/3694424/nyiso_regulation_req.pdf/6efc0df8-edc2-41bc-9e39-5fed576ba7bc

Decarbonization Scenario: Units' Utilization

```
OF              22,532,089.46_d
C_generation    20,849,062.23_d
C_no_load       1,682,977.24_d
C_SU            50.0000_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       0.0000_d
C_SUPP_vi       0.0000_d
```

```
- Units used:   261   (77.68%)
- Commitments: 12634  (52.22%)
- Start-ups:    232
- Shut-downs:   258
```

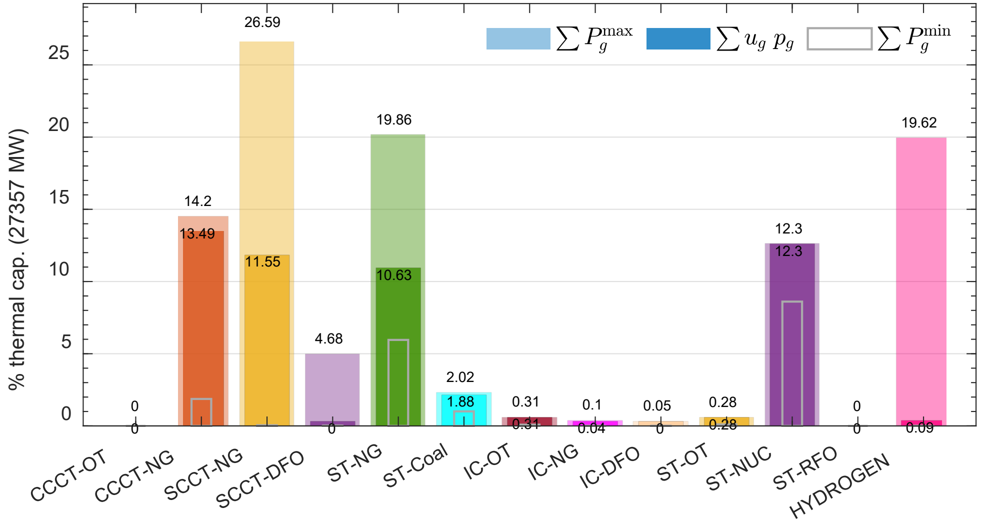


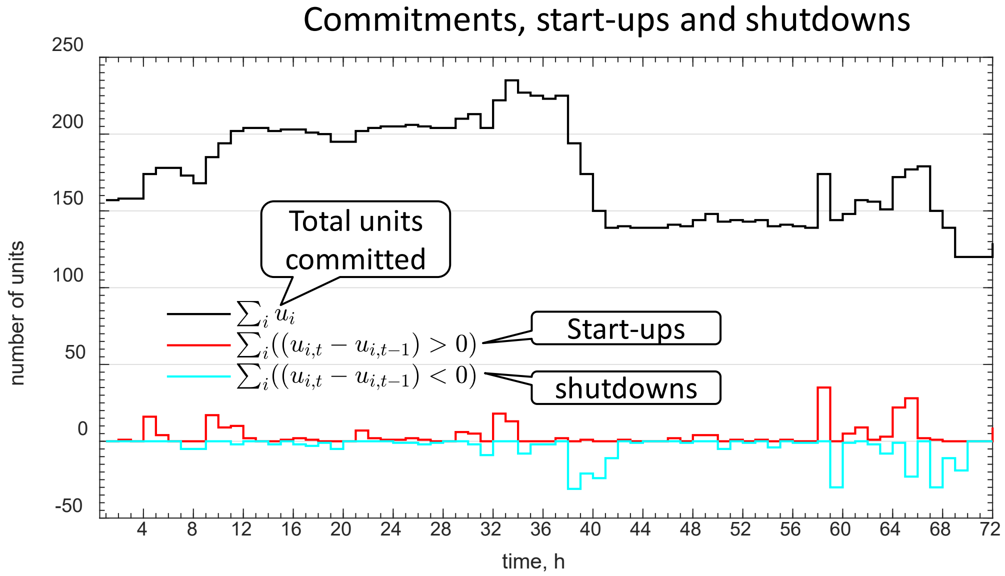
Net demand with storage

Net demand minus storage

headroom

footroom





Total units committed

Start-ups

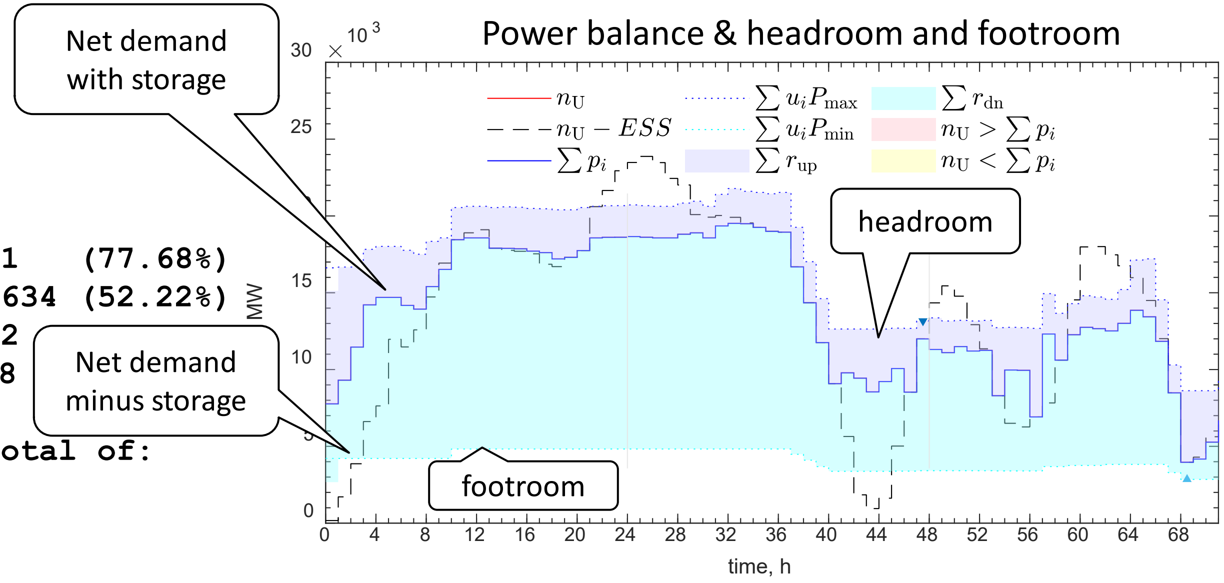
shutdowns

Decarbonization Scenario: Storage

```
OF              22,532,089.46_d
C_generation    20,849,062.23_d
C_no_load       1,682,977.24_d
C_SU            50.0000_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       0.0000_d
C_SUPP_vi       0.0000_d
```

```
- Units used:   261    (77.68%)
- Commitments: 12634  (52.22%)
- Start-ups:    232
- Shut-downs:  258

10 units with a total of:
- 6,912 MW
- 41,472 MWh (6h)
```

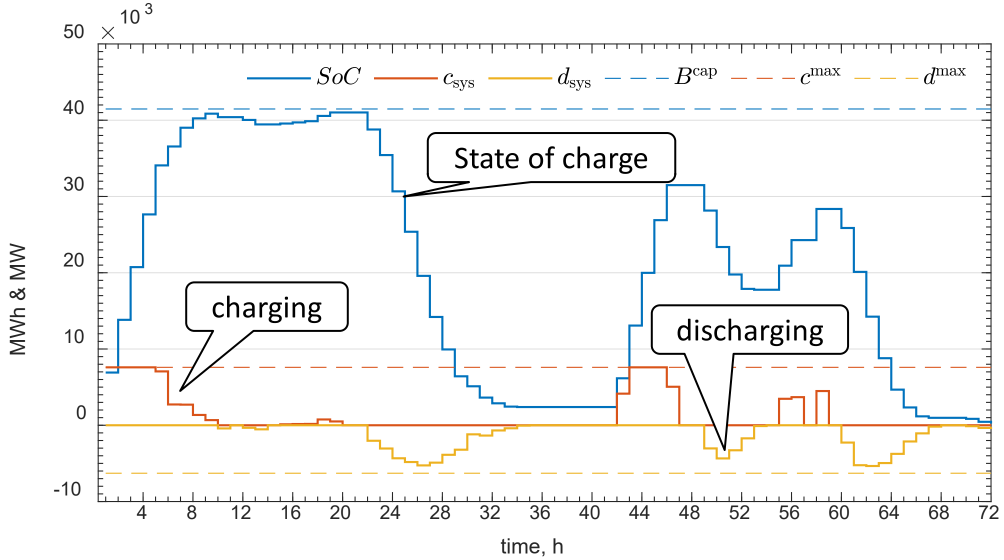


Net demand with storage

Net demand minus storage

headroom

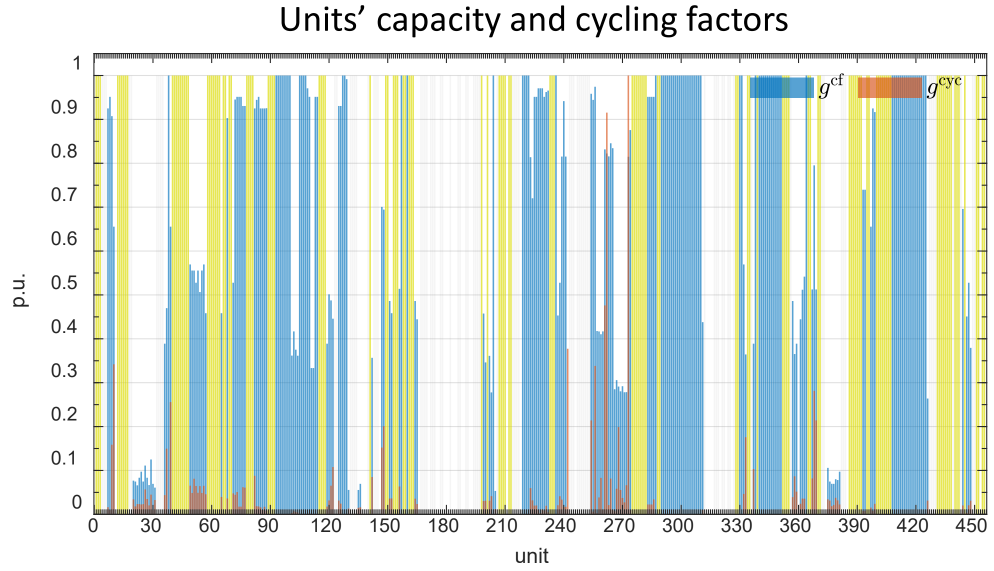
footroom



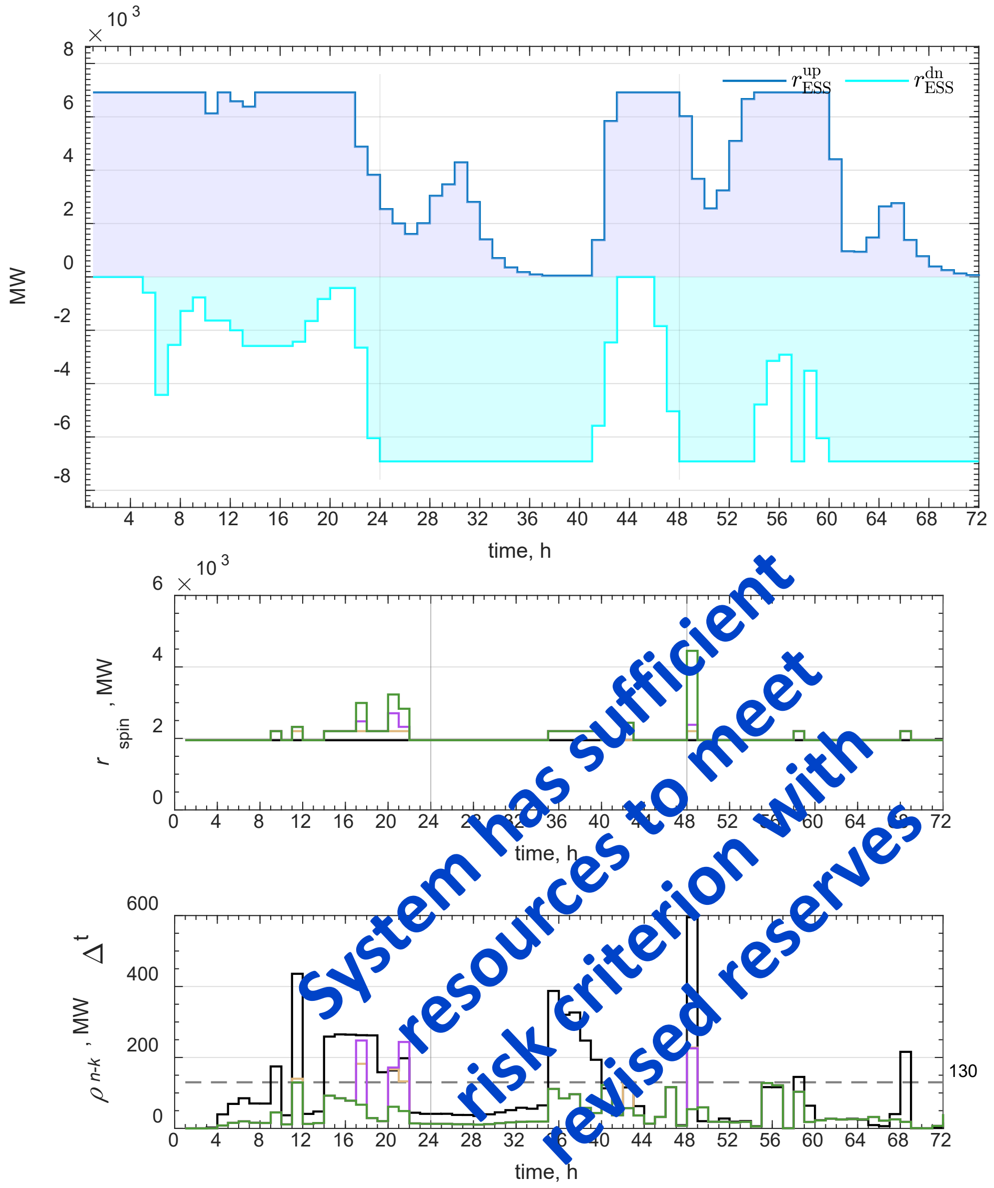
State of charge

charging

discharging

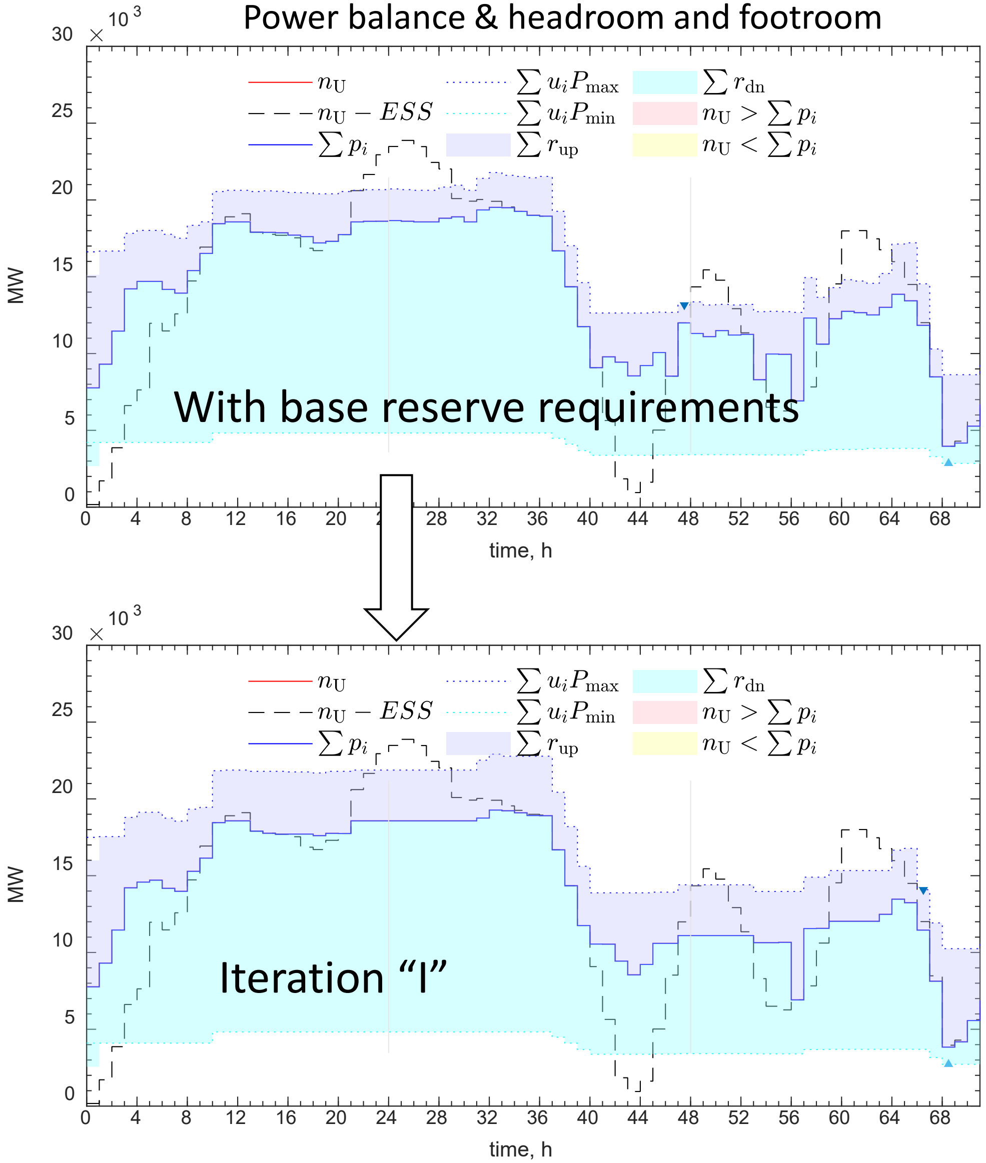


Decarbonization Scenario: Risk Compliance



System has sufficient resources to meet risk criterion with revised reserves

Power balance & headroom and footroom



With base reserve requirements

Iteration “I”

KEY INSIGHTS

Using Risk Analysis to Develop Robust Capacity Expansion Portfolios

- Operating risk is an important system specific metric to evaluate because it captures the dynamic nature of operating conditions (e.g., scheduling, dispatch, VRES, demand, and reliability of assets) and can be mitigated by smart and strategic scheduling of operating reserves.

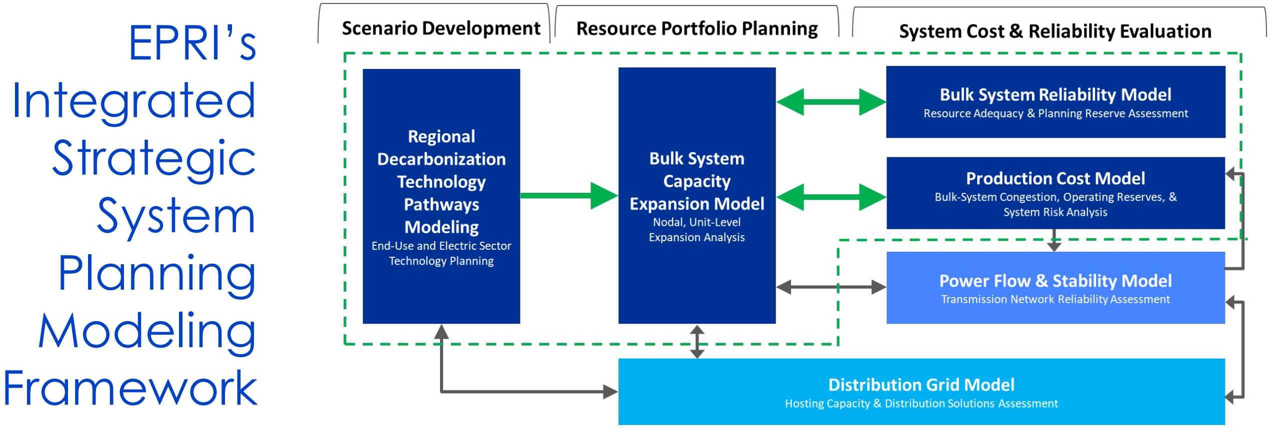
- Evaluating operating risk and mitigation strategies allows sending a feedback signal to capacity expansion planning tools to invest in more efficient and reliability enhancing resources.

- Energy storage technologies *can* be a double-edged sword. They can allow for efficient system operations and reduce stress during peaks but may also mask the need for other reserve providing resources, which can increase risk.

Concluding Remarks, Next Steps, & Future Research Opportunities

Concluding Remarks

- The research described in this presentation developed a portion of EPRI's Integrated Strategic System Planning Initiative's overall analytical modeling framework and toolbox (the links shown in green below)



- Comprehensive integrated system planning also requires evaluating reliability of the transmission network, and reliability of and opportunities for resource solutions (including non-wires alternatives) on the distribution system. These are described in other reports in the ISSP Technical Report series.
- Further, it requires informing the capacity expansion planning step with results from these evaluations to identify robust resource portfolios.

Next Steps

- Linking the PCMs used in this analysis with an AC powerflow tool to evaluate transmission reliability and stability with the new system buildout is a critical next step. PCM models typically use DC powerflow and cannot model the necessary transmission detail.
  - This step is detailed in a related ISSP Technical Report, "***Guidelines for Linking Power Flow Analysis with Production Cost Modeling Tools for Integrated Strategic System Planning: Needs, Screening Methods, and Best Practices***" (Product ID 3002028535)
- Improving understanding about potential distribution system solutions to reliably and cost effectively support decarbonization is another important next step.
  - The related ISSP Technical Report, "***Wide-Area Distribution Assessments for Integrated Strategic System Planning***" (Product ID 3002028536) describes this step, which uses information about future loads from US-REGEN to explore distribution opportunities.
- Finally, incorporating feedbacks from each of these analyses in the long-term bulk system capacity expansion planning model is necessary to "close the loop" for integrated system planning.
  - A summary of the full ISSP modeling approach, including feedbacks, is detailed in the related Technical Report, ***"Integrated Strategic System Planning Initiative: Modeling Framework, Demonstration Study Results, and Key Insights"*** (Product ID 3002027931)

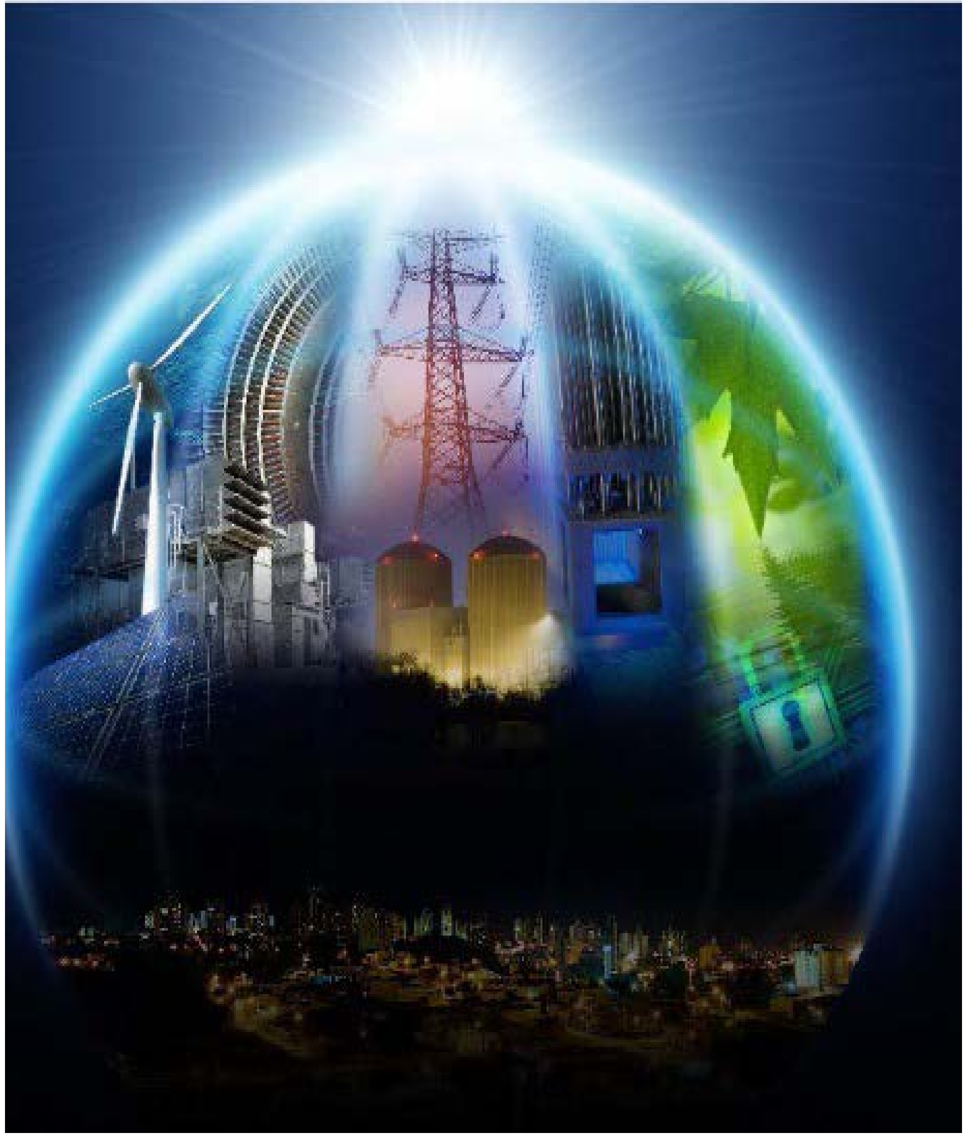
Future Research Opportunities

This research prompts several future research needs. Due to scope of this initial demonstration study, the following three key research gaps remain in comprehensively linking capacity expansion planning, resource adequacy, and production cost modeling tools:

(1) Understanding the role of regional markets and inter-regional electricity trade for cost-effective integrated system planning;

(2) Further defining the need for nodal vs. zonal bulk-system capacity expansion planning, and understanding the locational value of candidate resources in system planning; and

(3) Through additional scenarios, identifying the conditions under which comprehensive integrated system planning is truly needed, versus when more traditional approaches may be adequate.



Appendices

Appendix A

Additional US-REGEN Scenario Results

US-REGEN New York Energy Storage Deployment (2035)

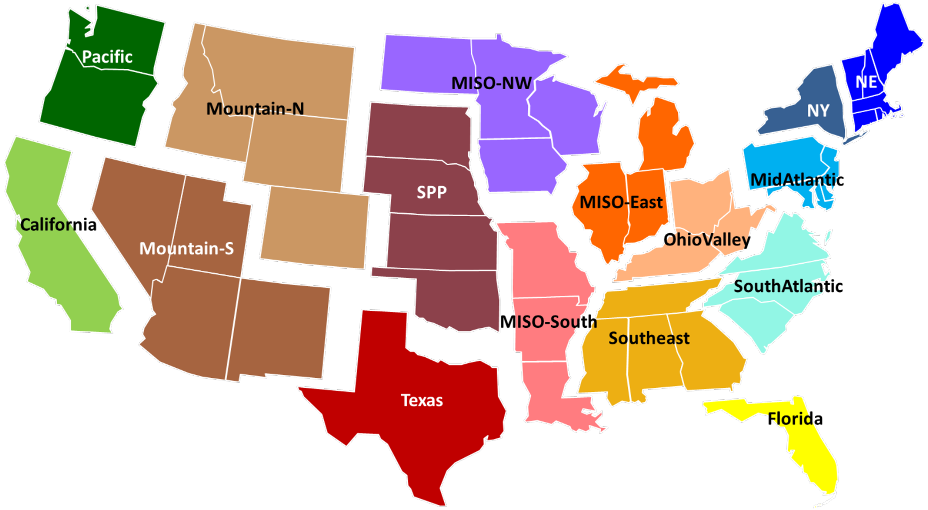
Scenario	**Energy Storage: Total Size of Door (GW)**		**Energy Storage: Total Size of Room (GWh)**		**Average Charge Duration (Hours)**	
	Li-Ion	Pumped Hydro	Li-Ion	Pumped Hydro	Li-Ion	Pumped Hydro
Reference	3	1.4	2.9	28.1	1	20
Accelerated Decarbonization	3	1.4	7.2	28.1	2.4	20

Notes:

- US-REGEN endogenously solves for the optimal size of the “room” and “door” for energy storage technologies.
- The primary energy storage pathways in NY are batteries (parameterized in the model as li-ion technology) and pumped hydro storage.
- All pumped hydro are existing installations.

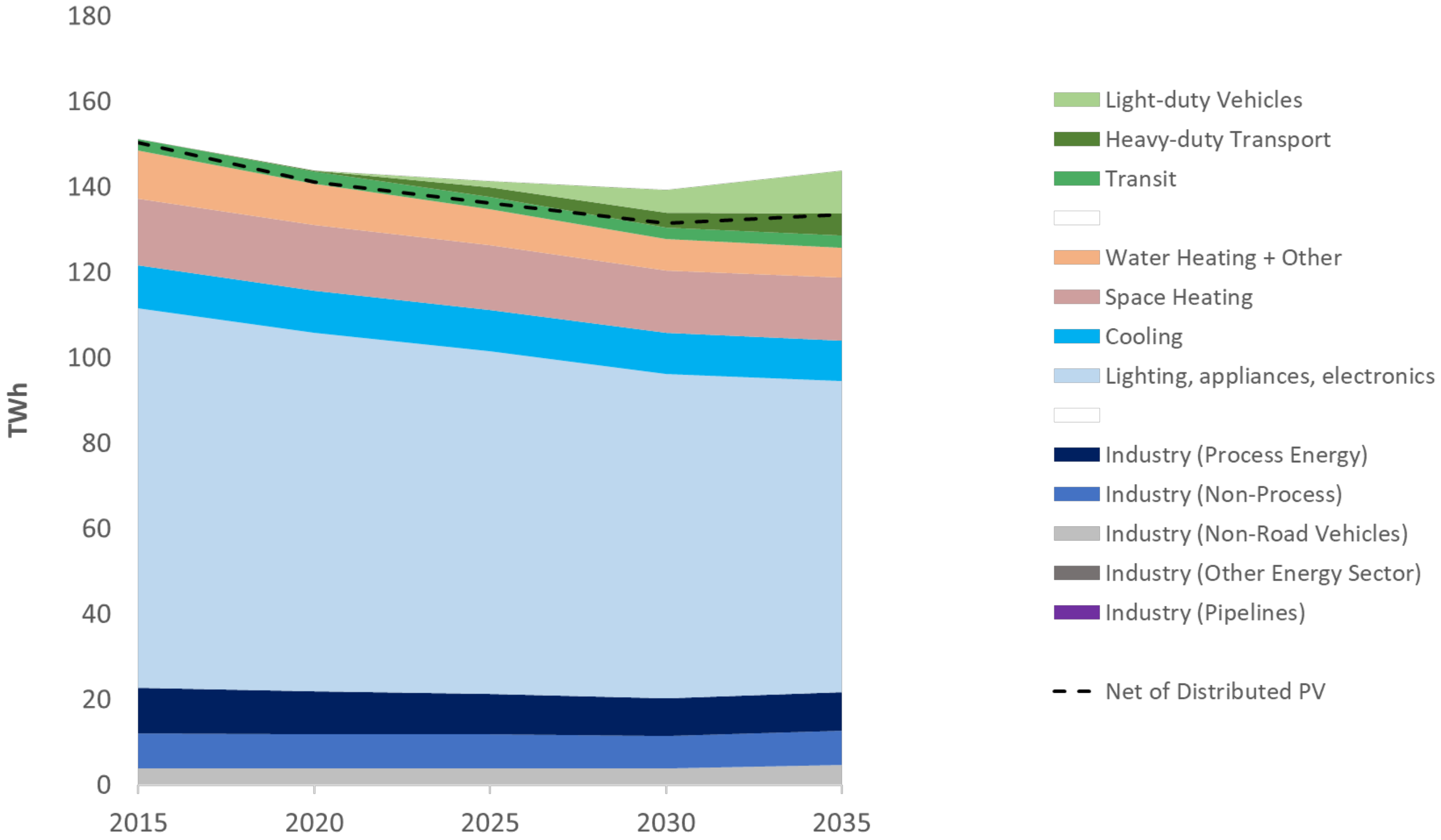
US-REGEN Inter-Regional Transmission Capacity Investments (GW) 2020-2035

Interstate Connection	US-REGEN Initial Capacities	Reference	Accelerated Decarbonization
New York – New England	1.9	0	0.2 (2020)
New York – MidAtlantic	2.4	0	1.0 (2020)



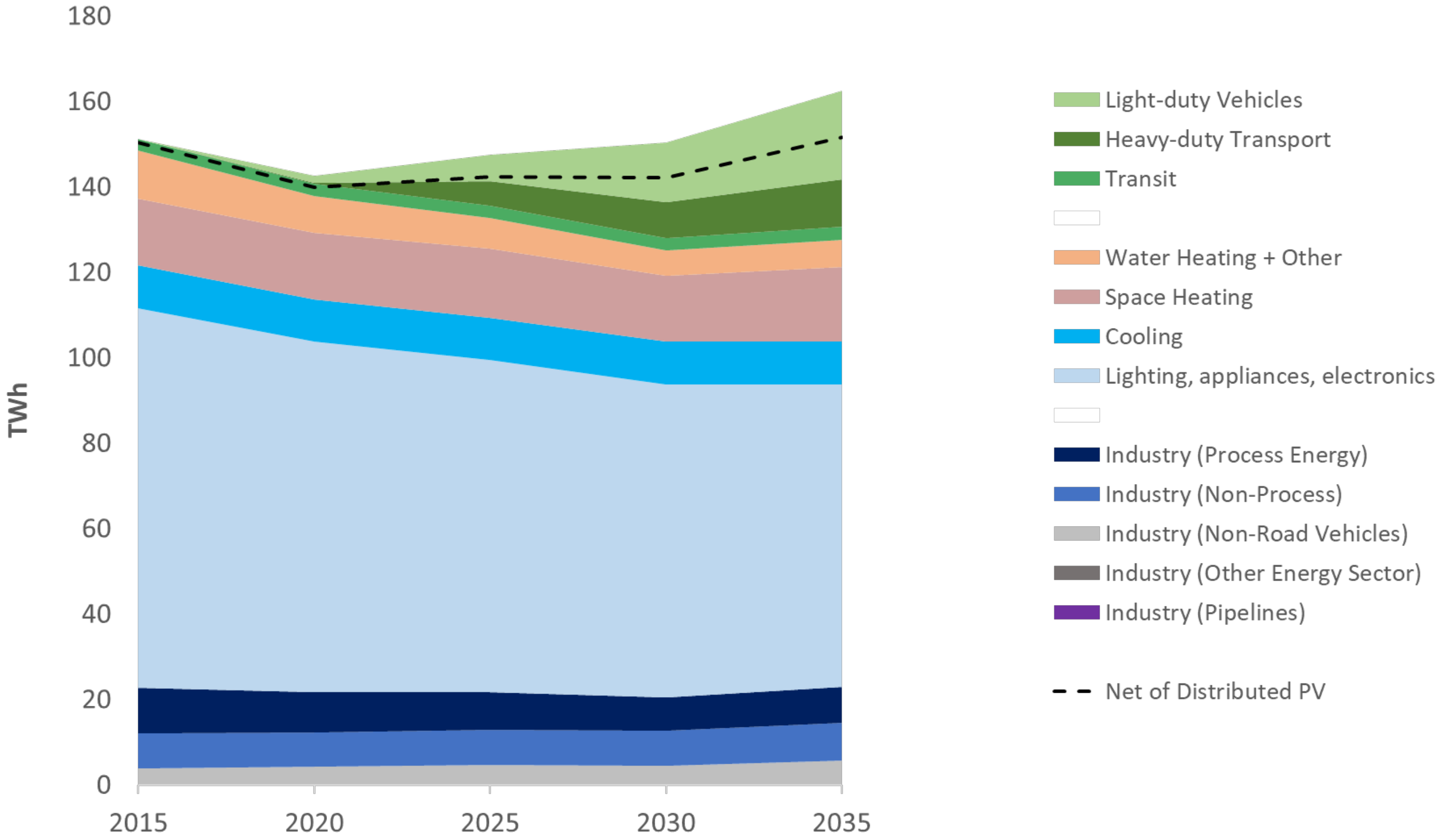
US-REGEN New York Load by End-Use Sector

Reference Scenario



US-REGEN New York Load by End-Use Sector

Accelerated Decarbonization Scenario

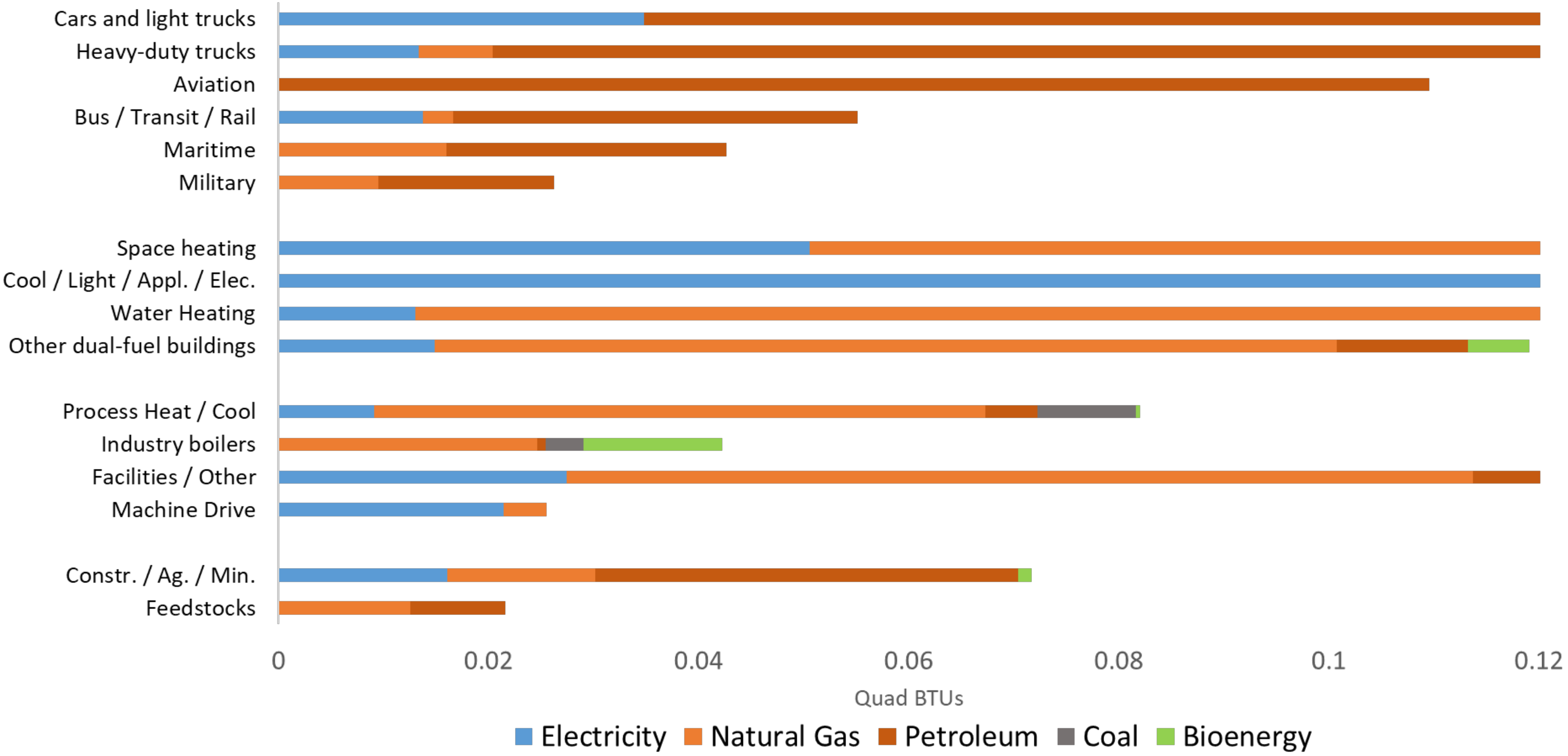


Key changes from Reference include much higher levels of transport electrification and space heating.

Slight increase in electric loads from industrial processes.

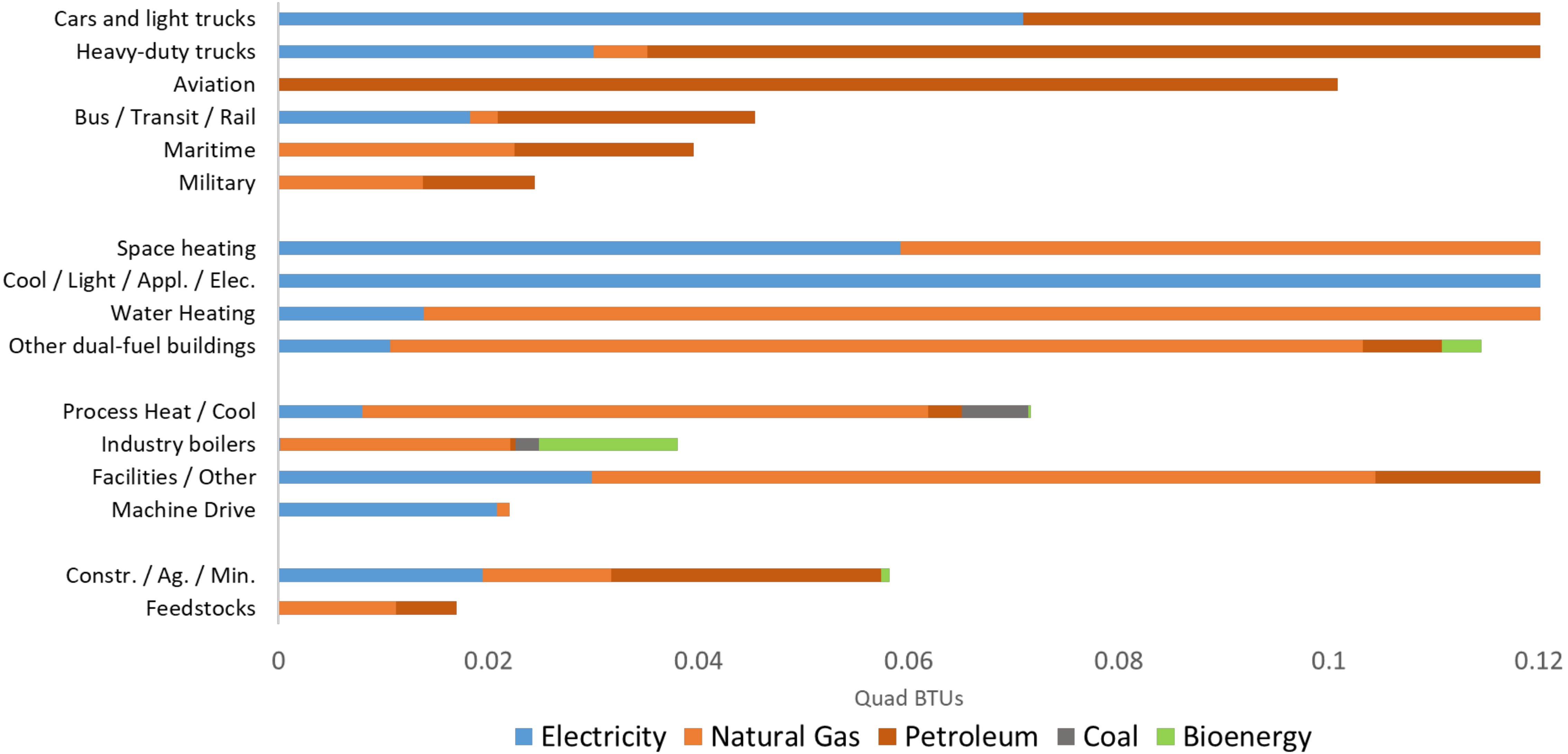
US-REGEN New York Final Energy Use (2035)

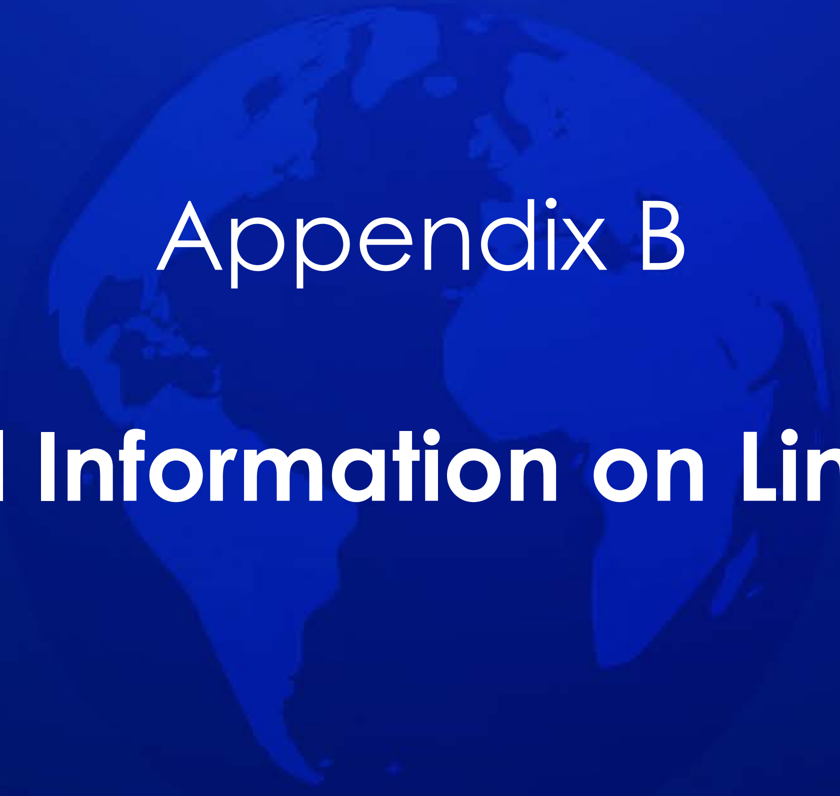
Reference Scenario



US-REGEN New York Final Energy Use (2035)

Accelerated Decarbonization Scenario



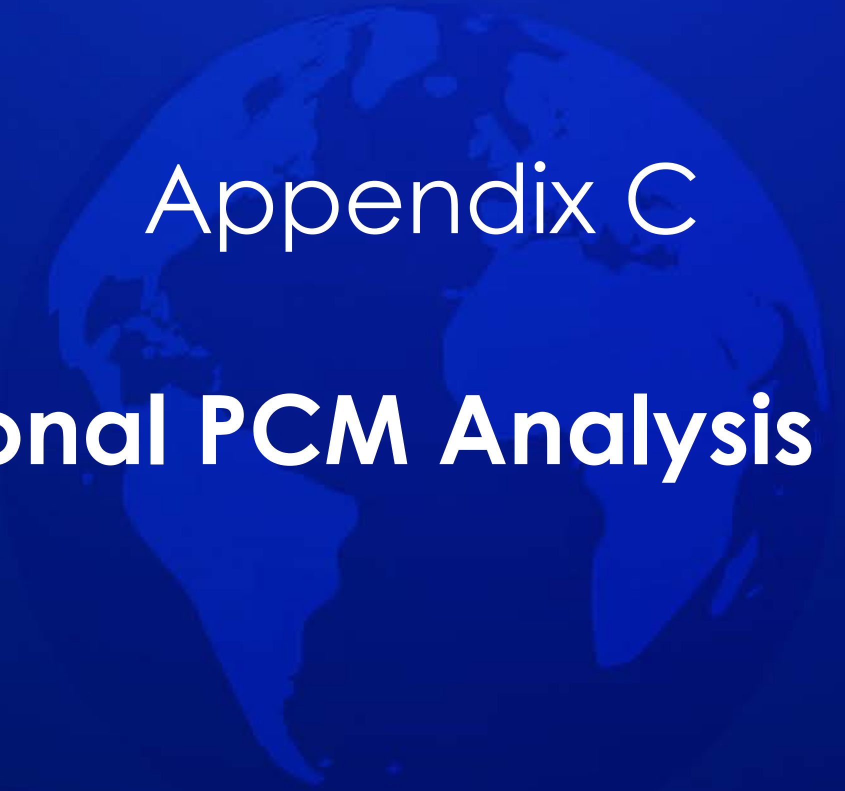


Appendix B

Additional Information on Linking Tools

List of Python Scripts to Transfer Data Between US-REGEN and PLEXOS LT

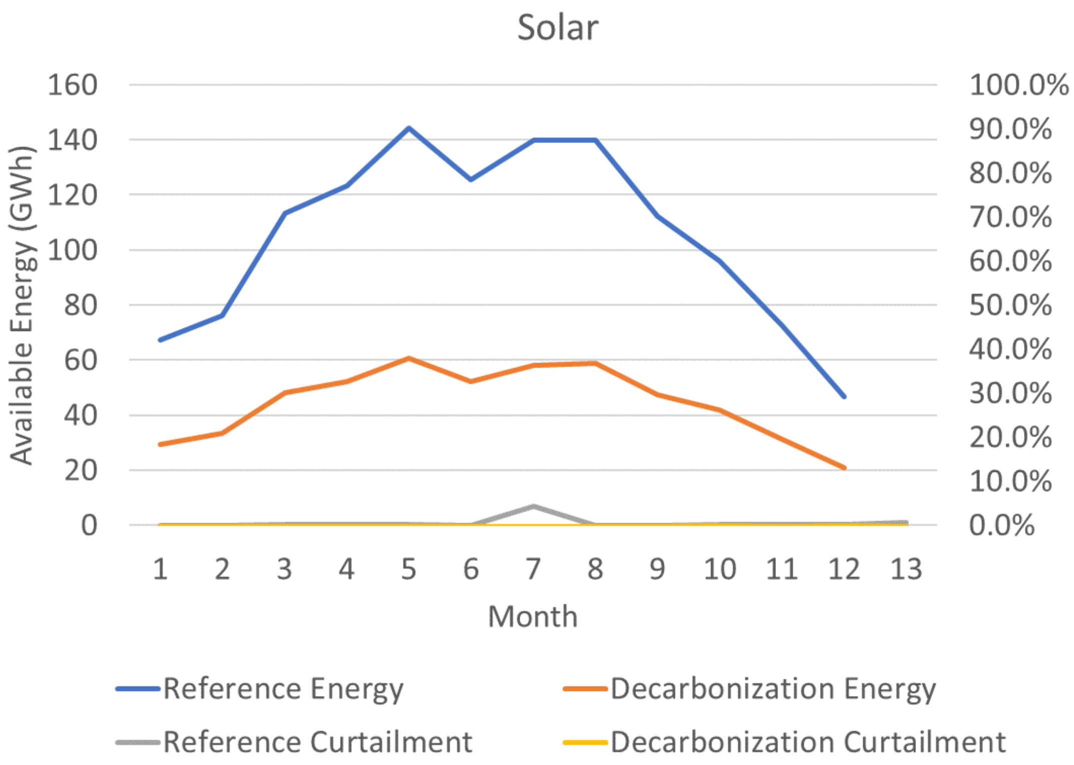
Solar/Wind Profiles	**Data:** Solar/wind profiles of the existing and future technologies at zonal level. **Script:** Maps US-REGEN regions to PLEXOS LT regions and assigns the wind/solar profiles to the corresponding existing and new units at the given regions. All the data is reformatted to PLEXOS data templates.
Load Profiles	**Data:** Regional level US-REGEN demand data **Script:** Maps US-REGEN regions to PLEXOS LT regions. Disaggregates the load to PLEXOS LT zones and reformats to PLEXOS data template.
Candidate Technologies	**Data:** Technology specific build cost, capacity limits, heat rates, and other costs. **Script:** Sites candidate technologies and maps PLEXOS LT technologies to US-REGEN technologies at regional level. All the technology level details are updated into PLEXOS database.
Aggregate Transmission	**Script:** Aggregates transmission to desired geographic level in PLEXOS
RPS Constraints and Reserve Margins	**Script:** Sets custom RPS constraints and Reserve margins in PLEXOS database based on US-REGEN's RPS constraints/feedback from reliability analysis.

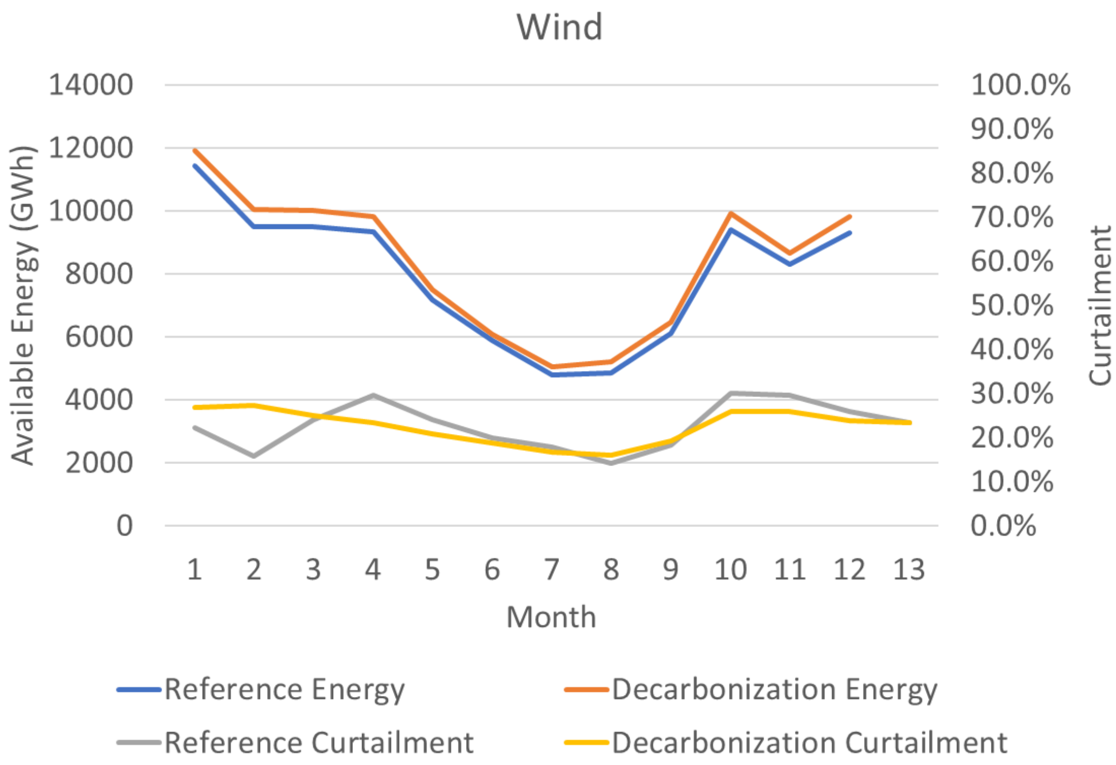


Appendix C

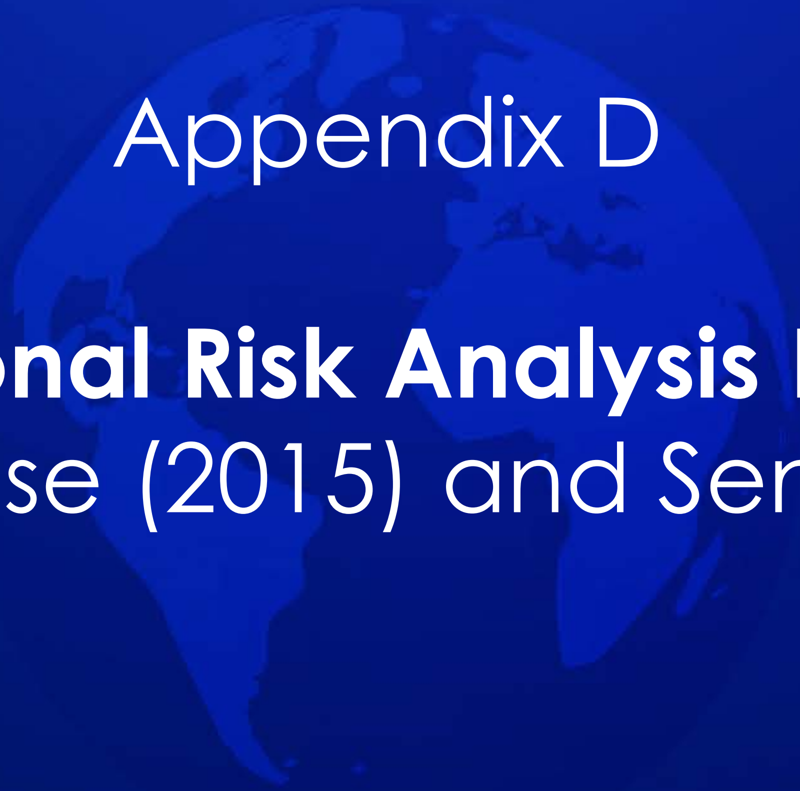
Additional PCM Analysis Results

PCM Modeling: Renewables curtailment





Solar has low levels of curtailment, while wind curtails about 23% of available energy in both cases



Appendix D

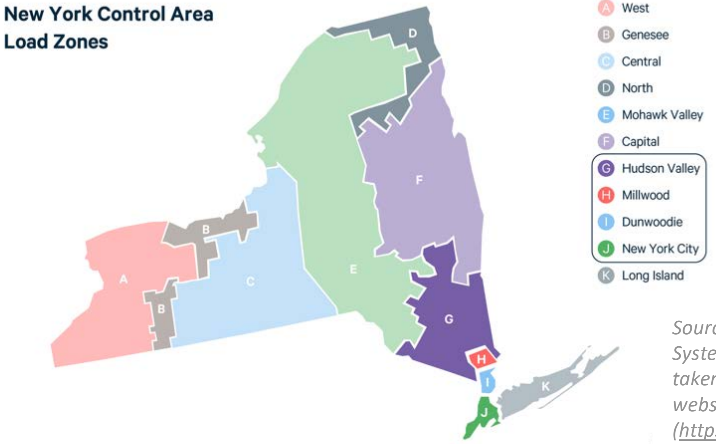
Additional Risk Analysis Results

Base Case (2015) and Sensitivities

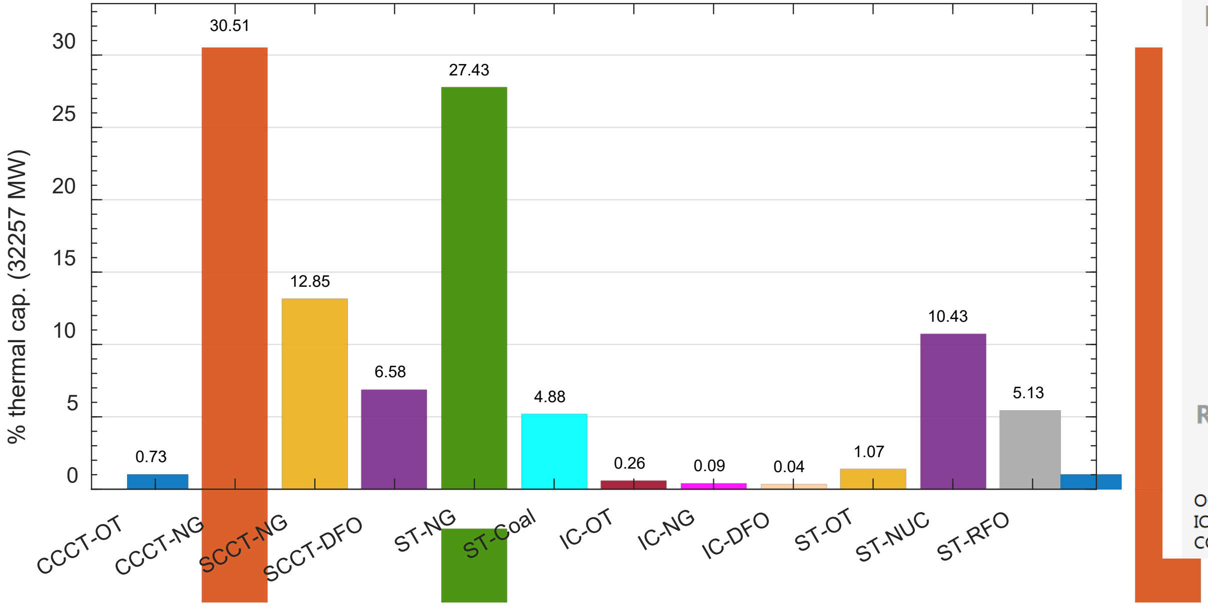
Base Case (2015)

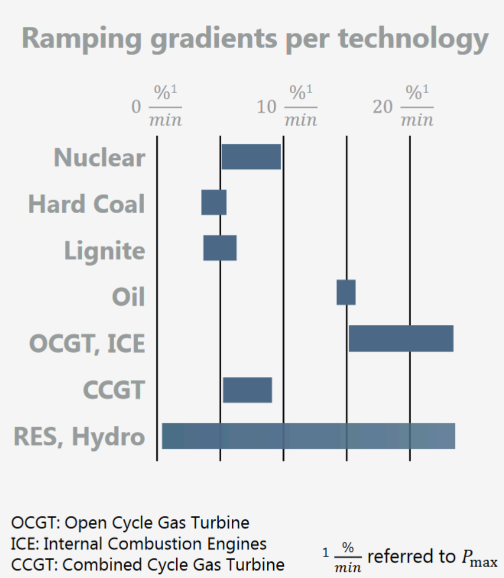
NYISO system, year 2015

- Data from Energy Exemplar
- Load = [9,920 30,120] MW
- Total thermal capacity 32,257 MW
- Total hydro production 5,816.9 MW

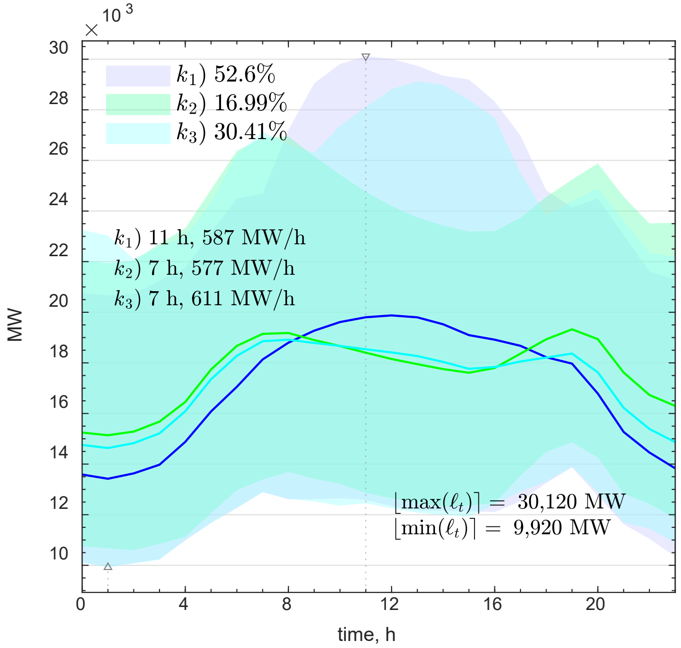


Source: New York Independent System Operator, NYISO map Image taken from Resource for the Future website, n.d. (https://www.resources.org/common-resources/buyer-side-mitigation-nyiso-another-mopr/) with permission.



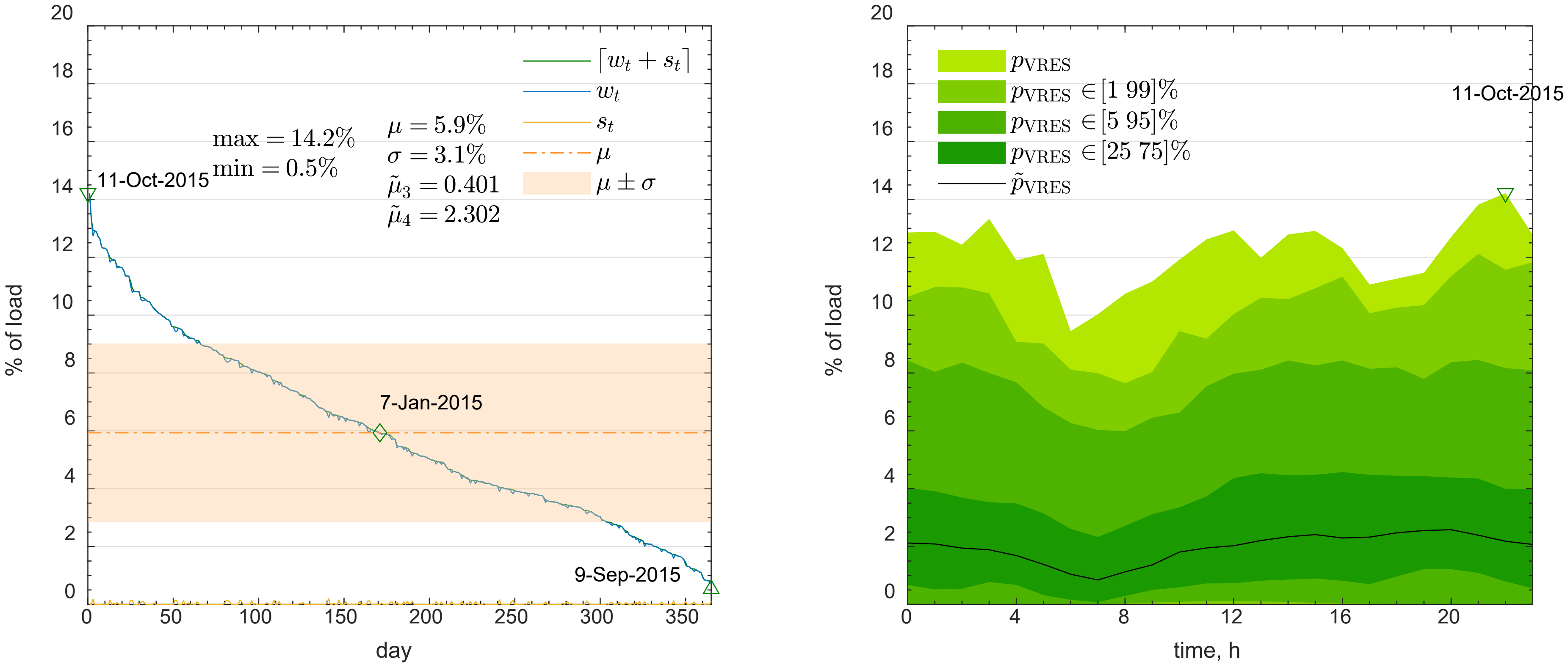


OCGT: Open Cycle Gas Turbine
ICE: Internal Combustion Engines
CCGT: Combined Cycle Gas Turbine



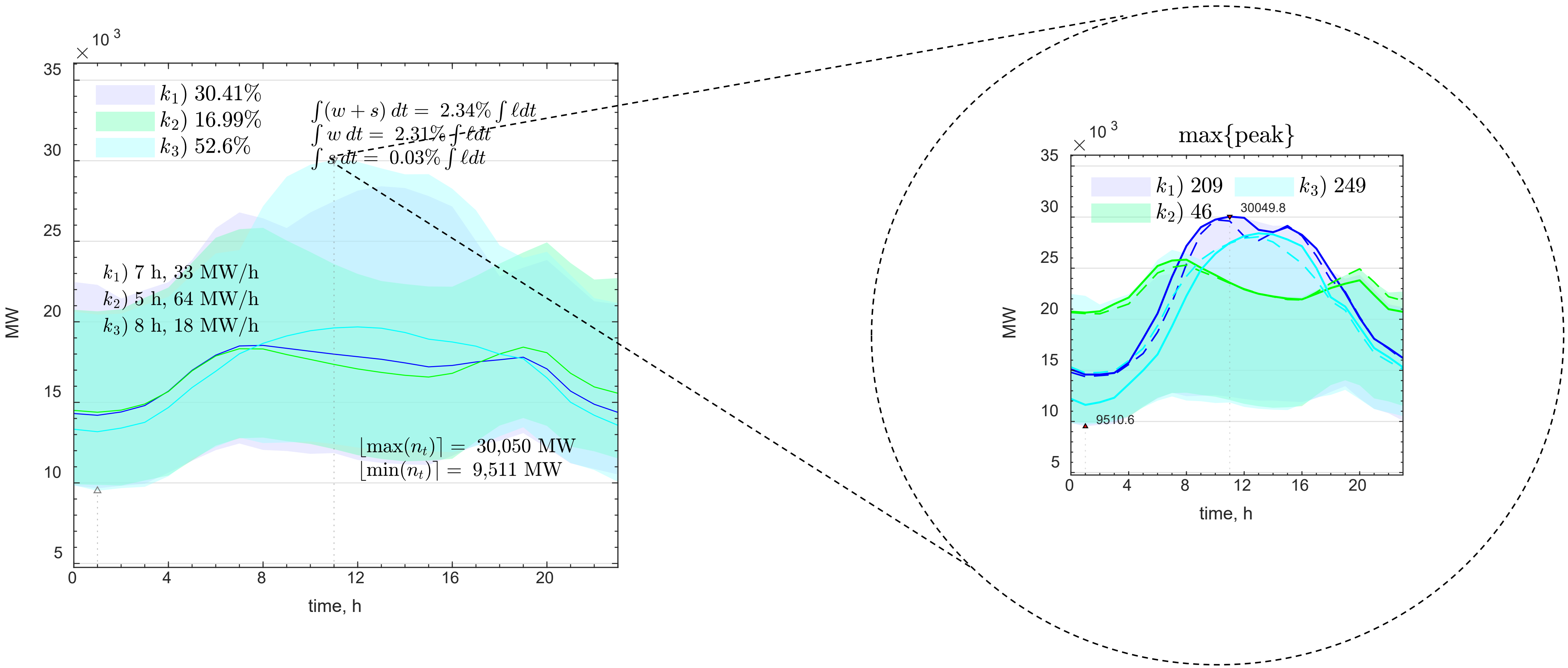
Variable Renewable Energy Sources

- Wind: 24 farms with a total of 1,749.6 MW
- Solar: 31.5 MW



Selection of Horizon of Study

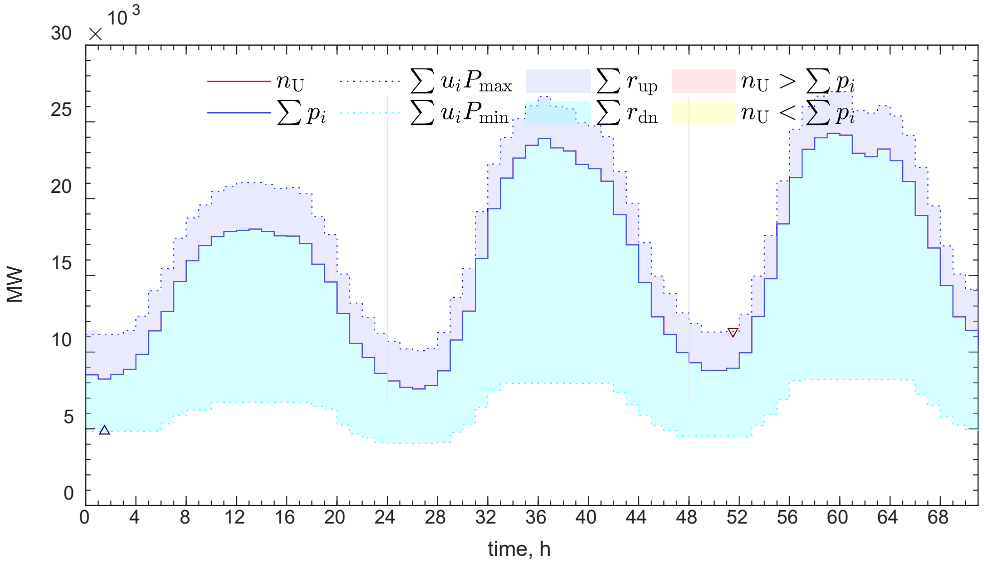
- Peak net load day chosen for testing (07/27/2015)

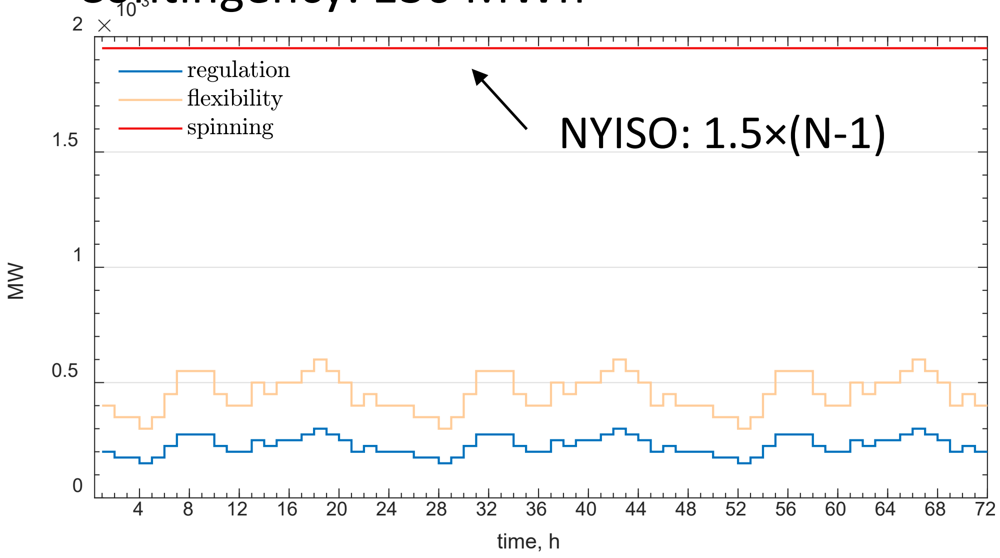


Base Case – Scheduling and Dispatch

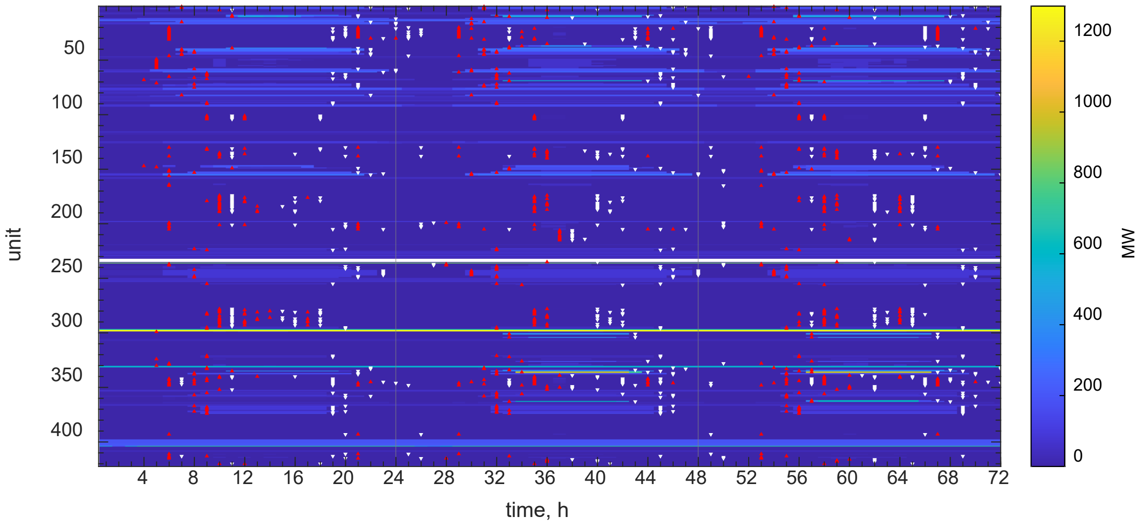
- Scheduling and dispatch:
  - Regulation*
  - Flexibility
  - Spinning (N-1 = 1298.7 MW)
- Risk
  - Flexibility: 10 MWh
  - Contingency: 130 MWh

```
VoLL  = 15,000 $/MWh
PRegu = 13,200 $/MW
Pflex = 13,100 $/MW
PSpin = 13,000 $/MW
```





NYISO: 1.5×(N-1)

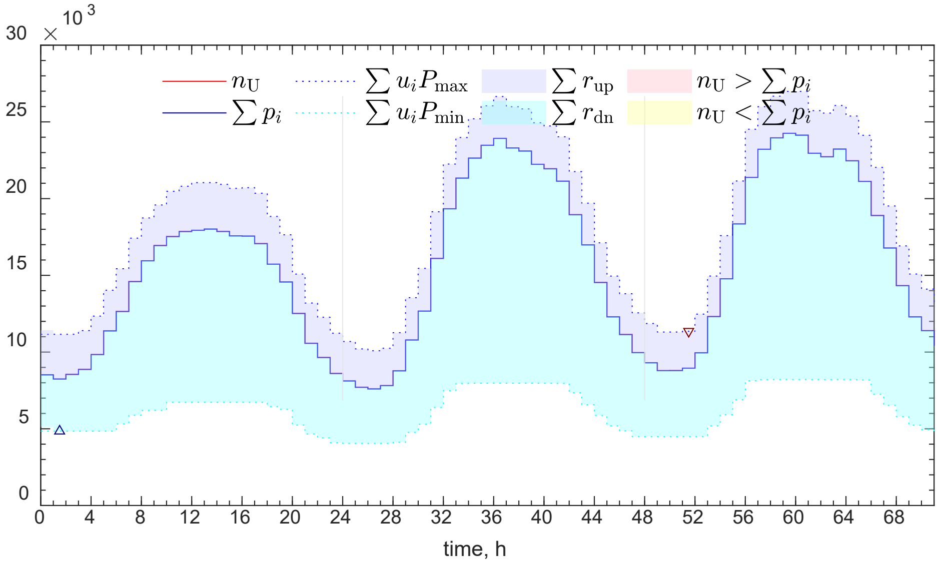


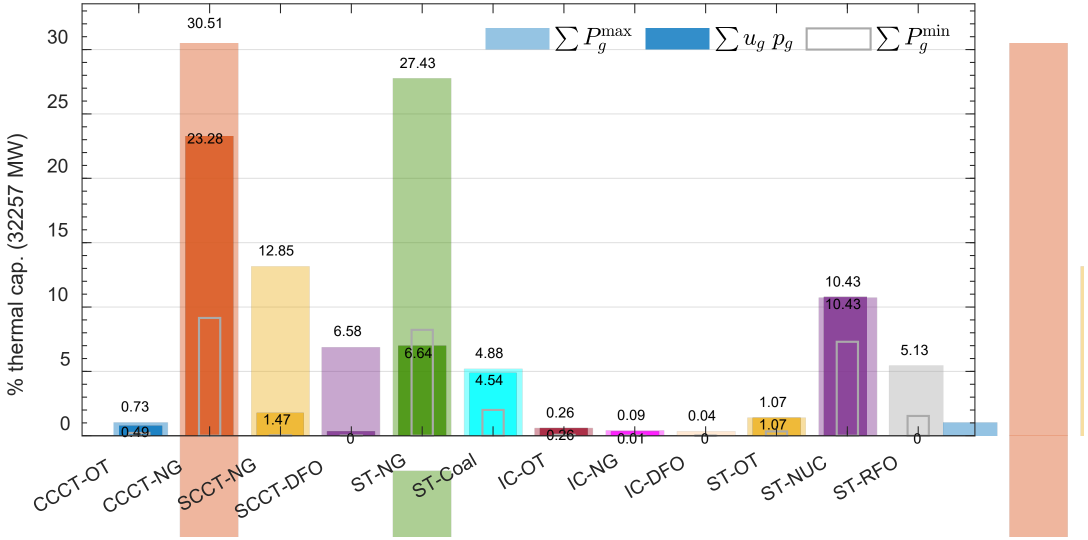
*https://www.nyiso.com/documents/20142/3694424/nyiso_regulation_req.pdf/6efc0df8-edc2-41bc-9e39-5fed576ba7bc

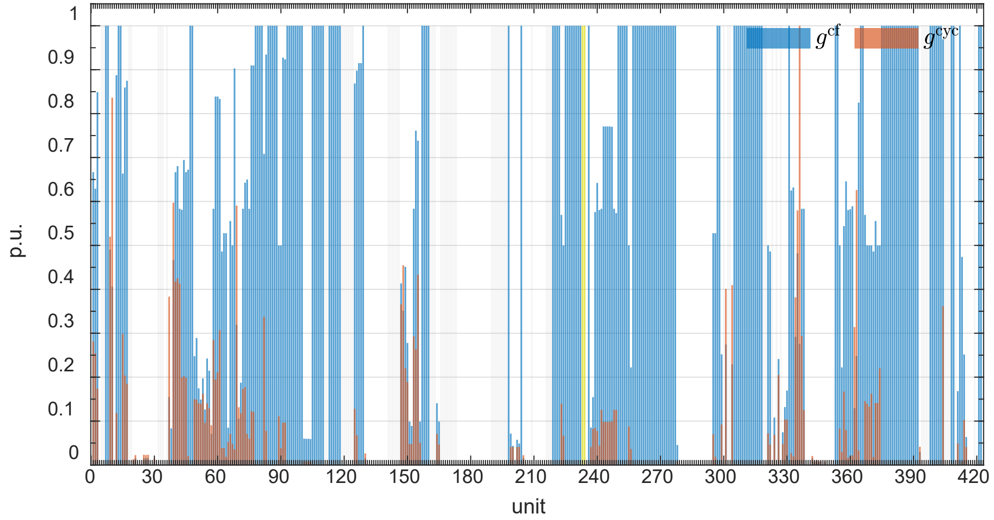
Base Case – Capacity Utilization and Risk

```
C_generation    18,985,102.5638_d
C_no_load       3,271,108.5137_d
C_SU            367,475.1400_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       70889.0000_d – (5.4 MW)
```

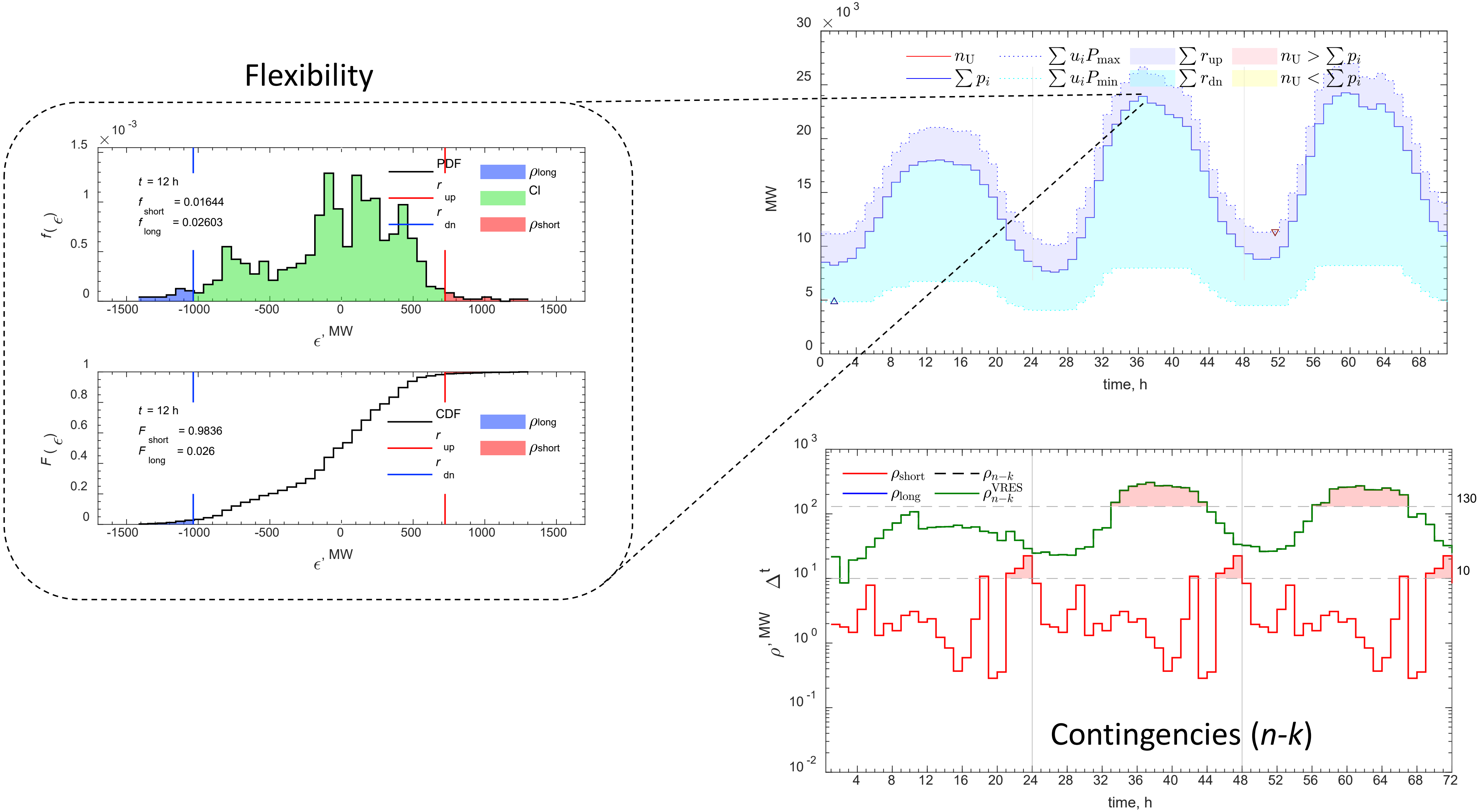
```
- Units used:   358    (84.83%)
- Commitments: 18014   (59.29%)
- Start-ups:    681
- Shut-downs:   640
```





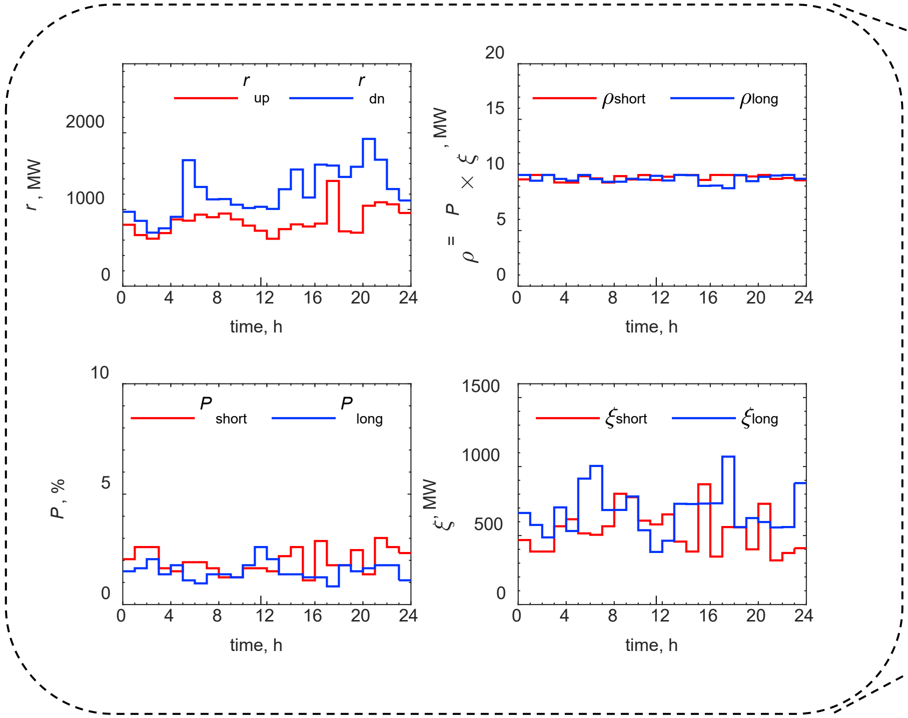


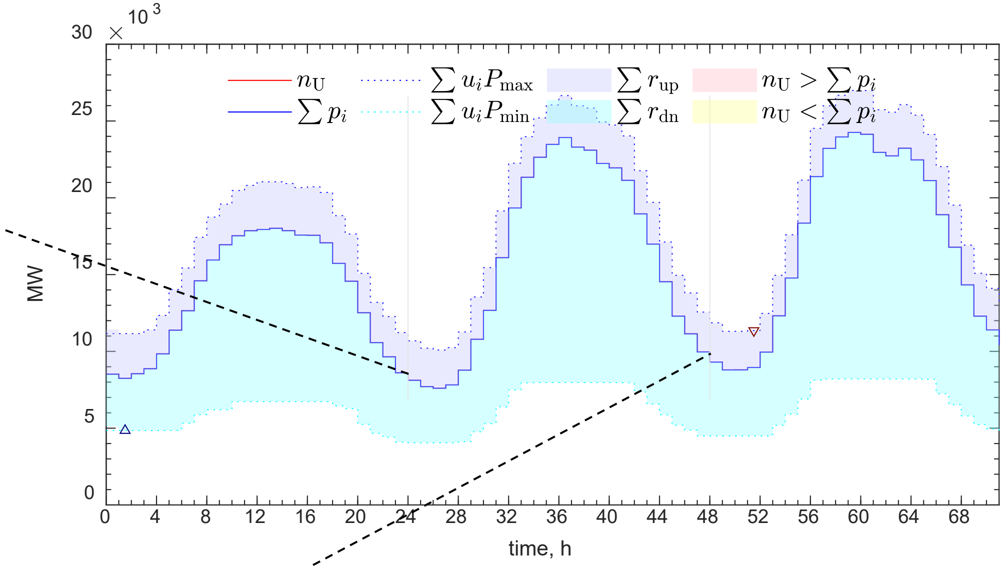
Risk Assessment

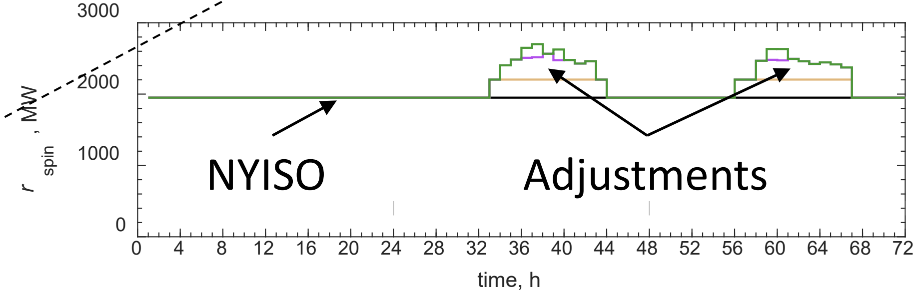


Adjustments to Meet Risk Ceiling ($\rho_{\text{flex}} = 10$ $\rho_{\text{n-k}} = 130$)

Flexibility

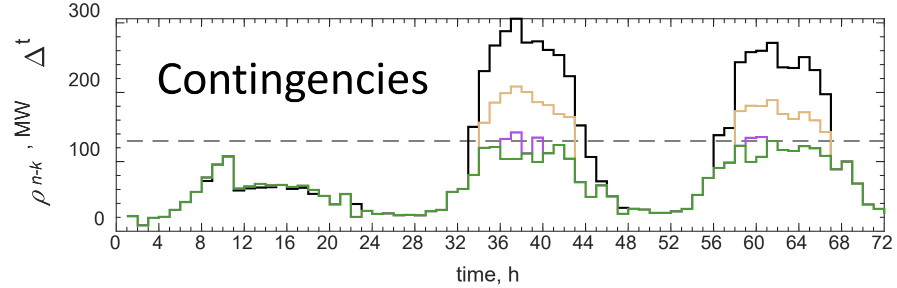






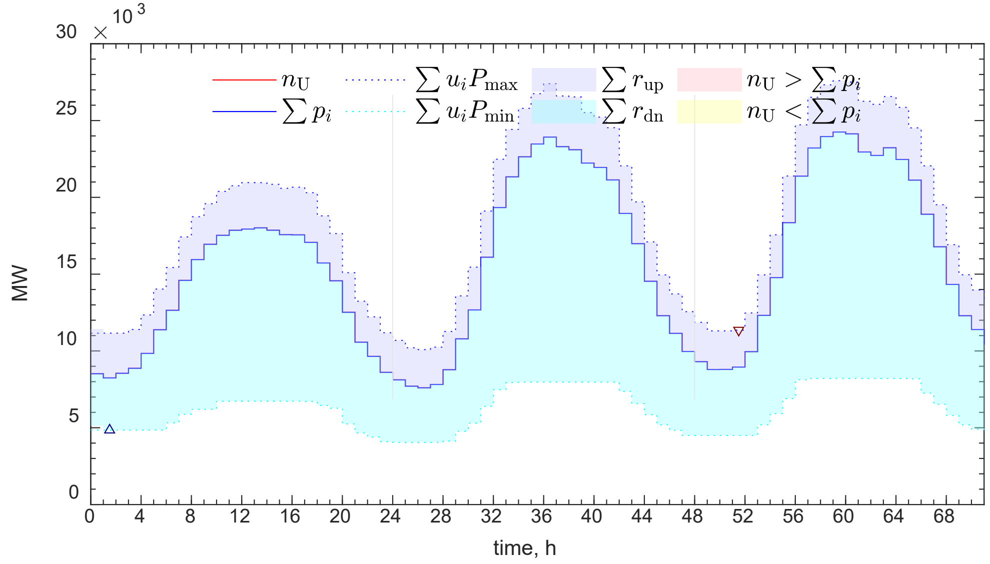
Gradient search method:

$$\Delta r = \left(\rho^{\text{target}} - \rho^{i}\right)\frac{r^{i} - r^{i-1}}{\rho^{i} - \rho^{i-1}}$$



Impact to System Operation

```
C_generation   18,987,708.4604_d
C_no_load      3,268,471.7857_d
C_SU           367,475.1400_d
C_ENS          0.0000_d
C_WIND_SPILLED 0.0000_d
C_PV_CURT      0.0000_d
C_RTPV_CURT    0.0000_d
C_REG_vi       0.0000_d
C_FLEX_vi      0.0000_d
C_SPIN_vi      0.0000_d
```



```
C_generation   18,985,102.5638_d
C_no_load      3,271,108.5137_d
C_SU           367,475.1400_d
C_ENS          0.0000_d
C_WIND_SPILLED 0.0000_d
C_PV_CURT      0.0000_d
C_RTPV_CURT    0.0000_d
C_REG_vi       0.0000_d
C_FLEX_vi      0.0000_d
C_SPIN_vi      70889.0000_d – (5.4 MW)
```

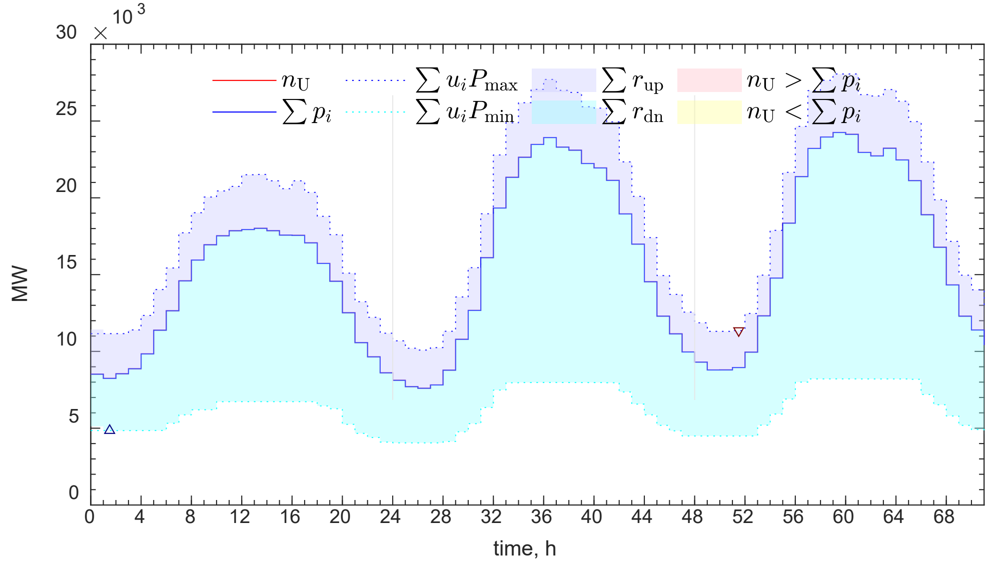
The system has sufficient installed capacity to meet risk ceiling with available resources.

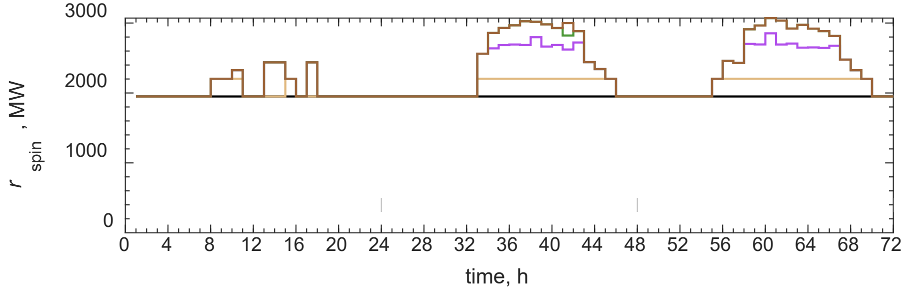
No need to trigger a new EP determination.

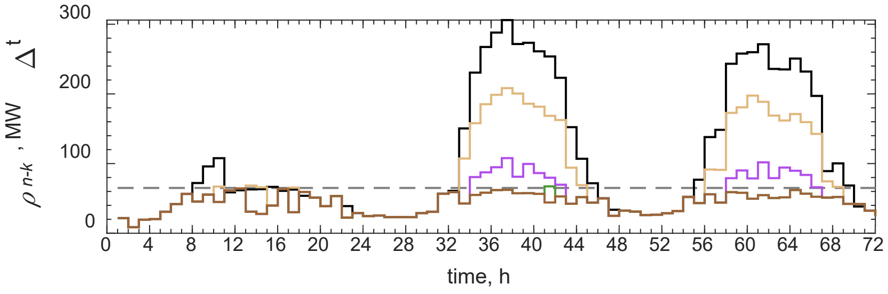
Tightening Risk Ceilings (ρ_{flex} = 5 ρ_{n-k} = 65)

```
C_generation   18,989,141.6925_d
C_no_load      3,265,181.9322_d
C_SU           367,475.1400_d
C_ENS          0.0000_d
C_WIND_SPILLED 0.0000_d
C_PV_CURT      0.0000_d
C_RTPV_CURT    0.0000_d
C_REG_vi       0.0000_d
C_FLEX_vi      0.0000_d
C_SPIN_vi      0.0000_d
```

```
C_generation   18,985,102.5638_d
C_no_load      3,271,108.5137_d
C_SU           367,475.1400_d
C_ENS          0.0000_d
C_WIND_SPILLED 0.0000_d
C_PV_CURT      0.0000_d
C_RTPV_CURT    0.0000_d
C_REG_vi       0.0000_d
C_FLEX_vi      0.0000_d
C_SPIN_vi      70889.0000_d - (5.4 MW)
```



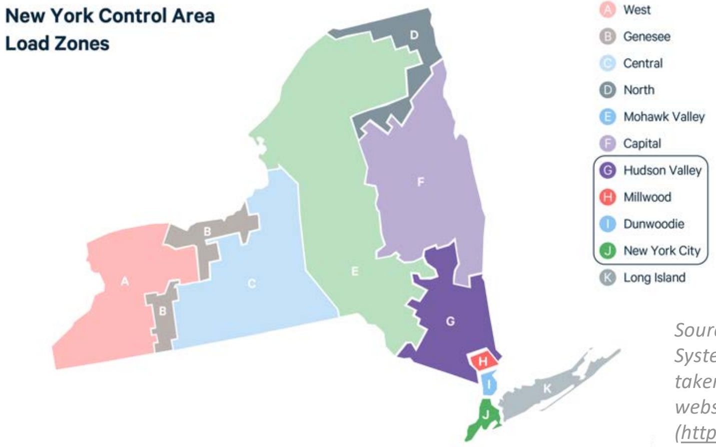




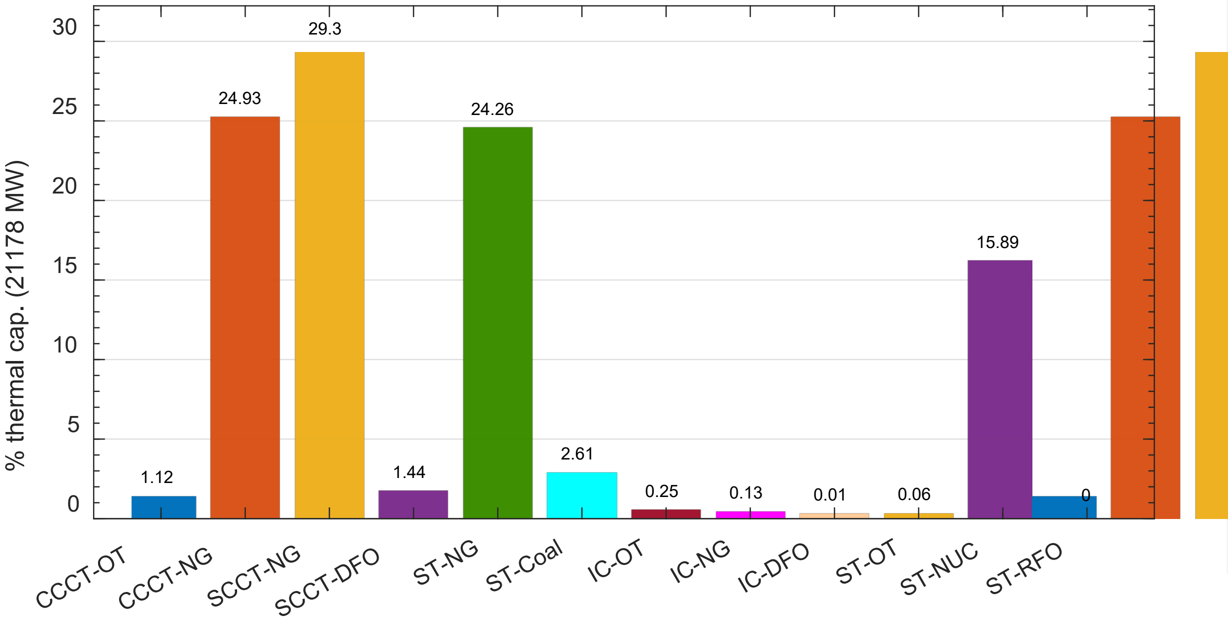
Reference Case (with Lower Reserves & 1h Storage) (2035)

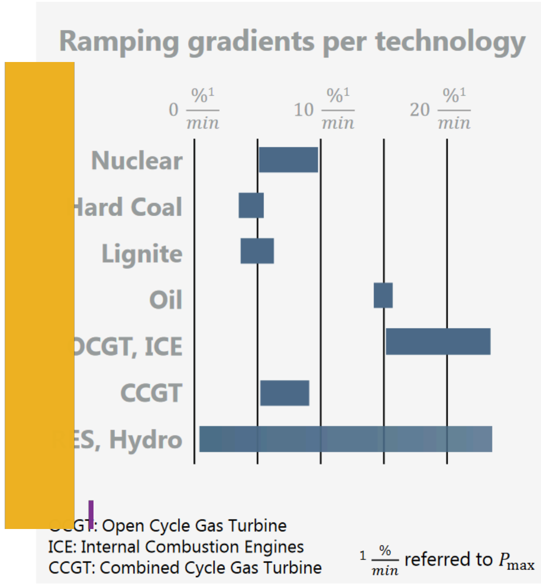
NYISO system, year 2035

- Data from Energy Exemplar & **US Regen**
- Load = [9,670 29,470] MW
- Total thermal capacity 21,178 MW
- Total hydro production 5,816.9 MW



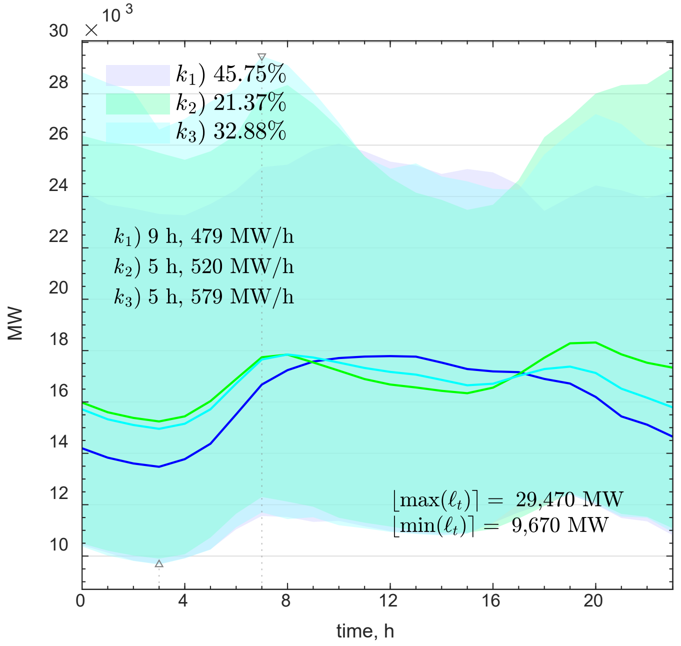
Source: New York Independent System Operator, NYISO map Image taken from Resource for the Future website, n.d. (https://www.resources.org/common-resources/buyer-side-mitigation-nyiso-another-mopr/) with permission.





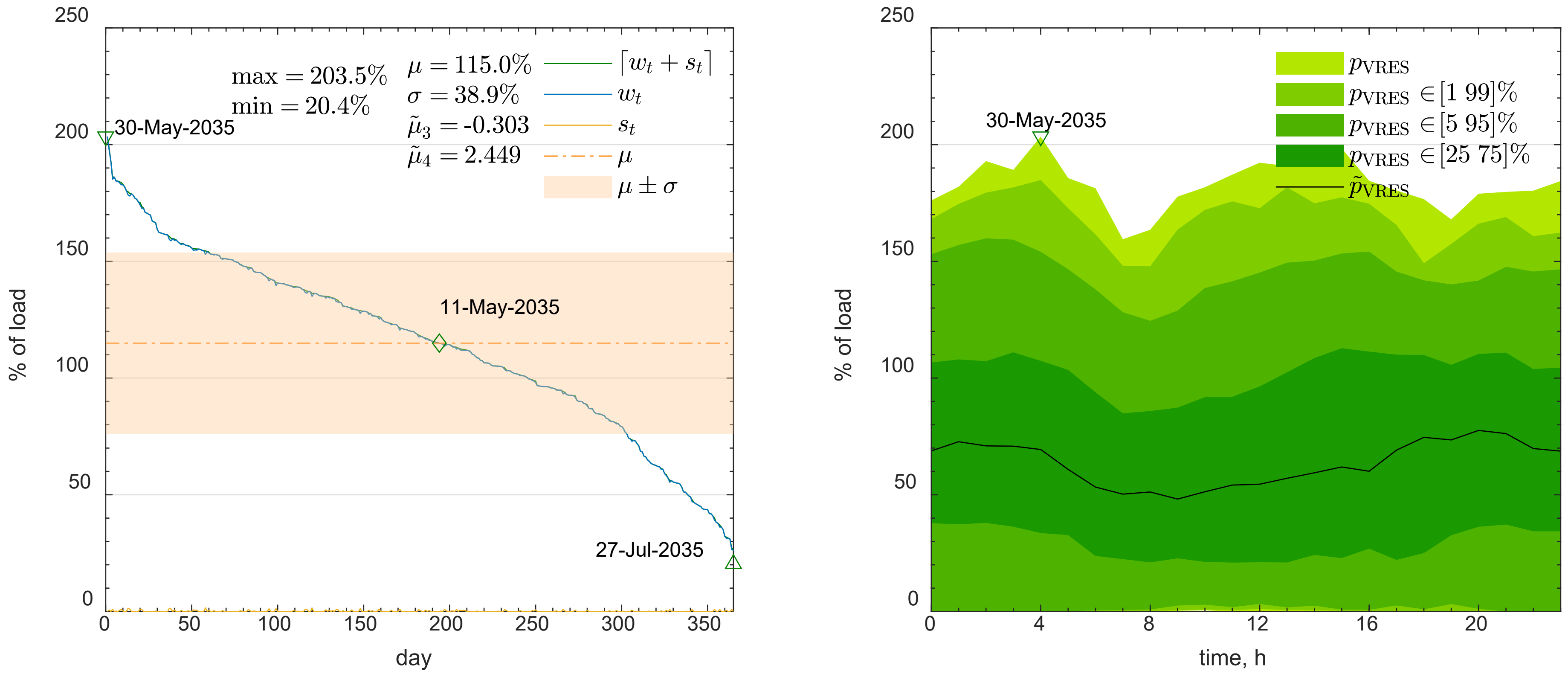
OCGT: Open Cycle Gas Turbine
ICE: Internal Combustion Engines
CCGT: Combined Cycle Gas Turbine

$^1 \frac{\%}{min}$ referred to $P_{\max}$



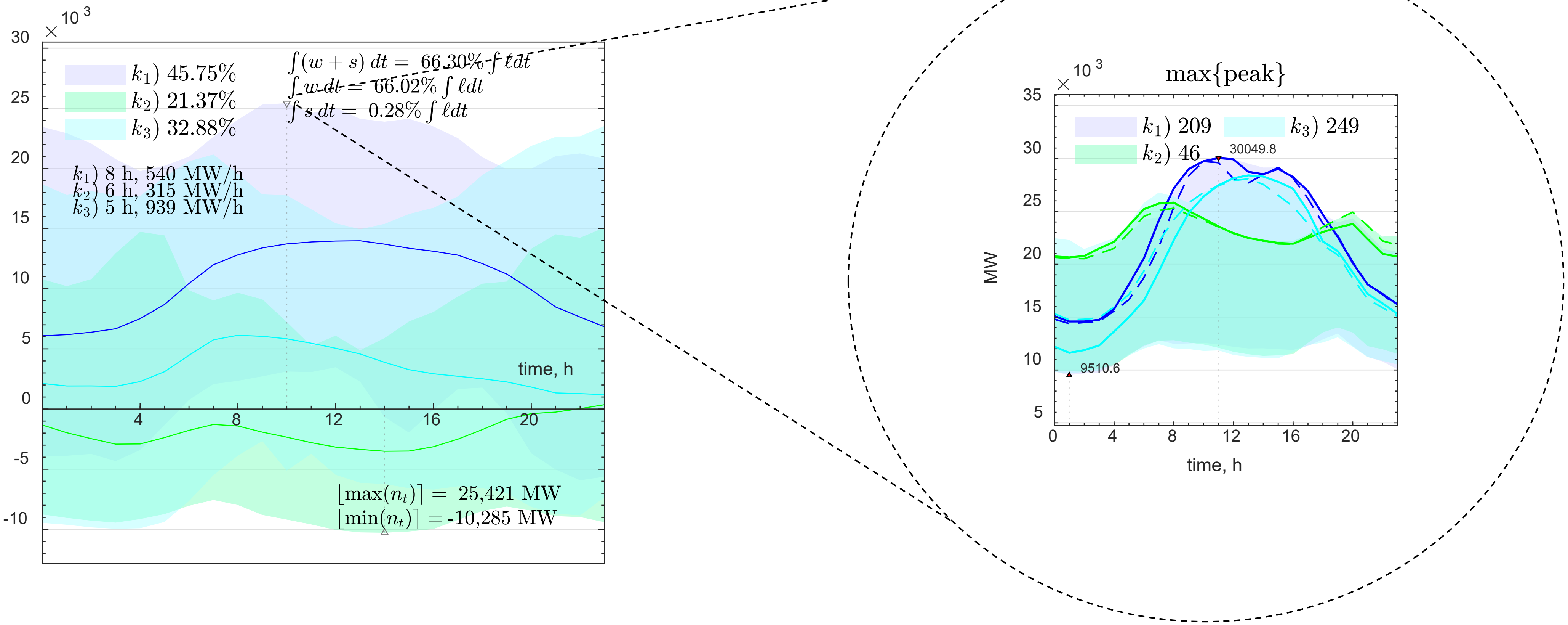
Variable Renewable Energy Sources

- Wind: 25,478 MW
- Solar: 227.9 MW



Selection of Horizon of Study

- Peak net load day chosen for testing 209, (07/27/2035).
  - Omitting hydro generation, since it is constant



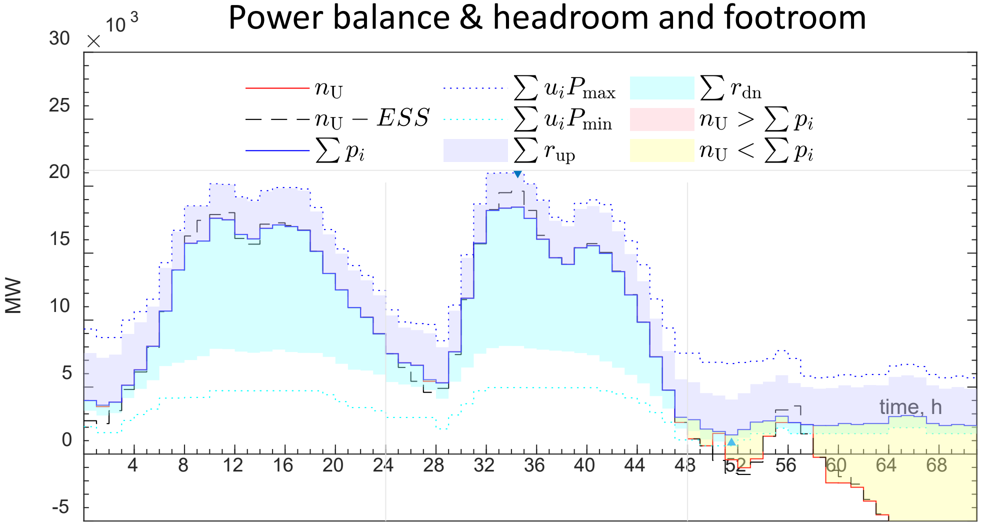
Reference Case (with VRES and Storage with no A/S) (2035)

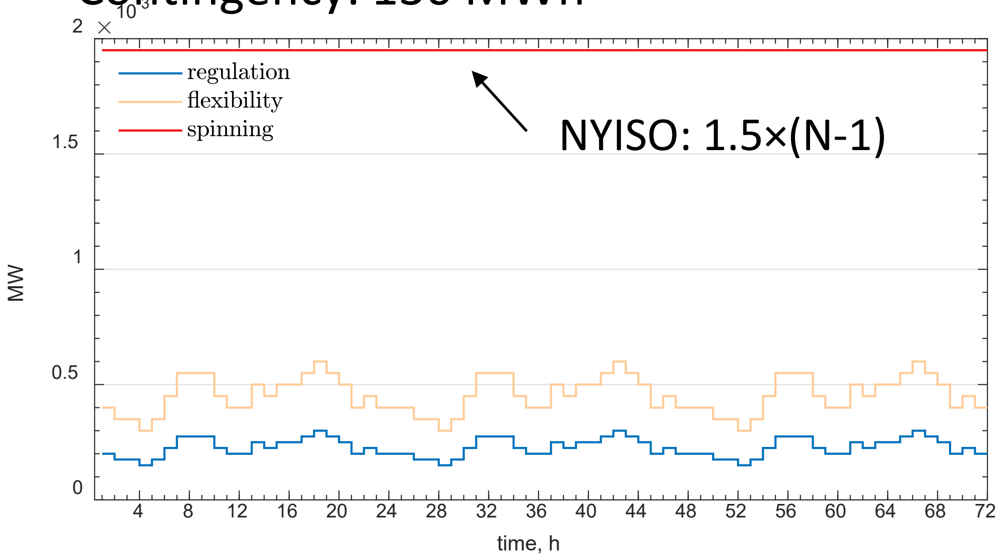
Generation Scheduling and Dispatch

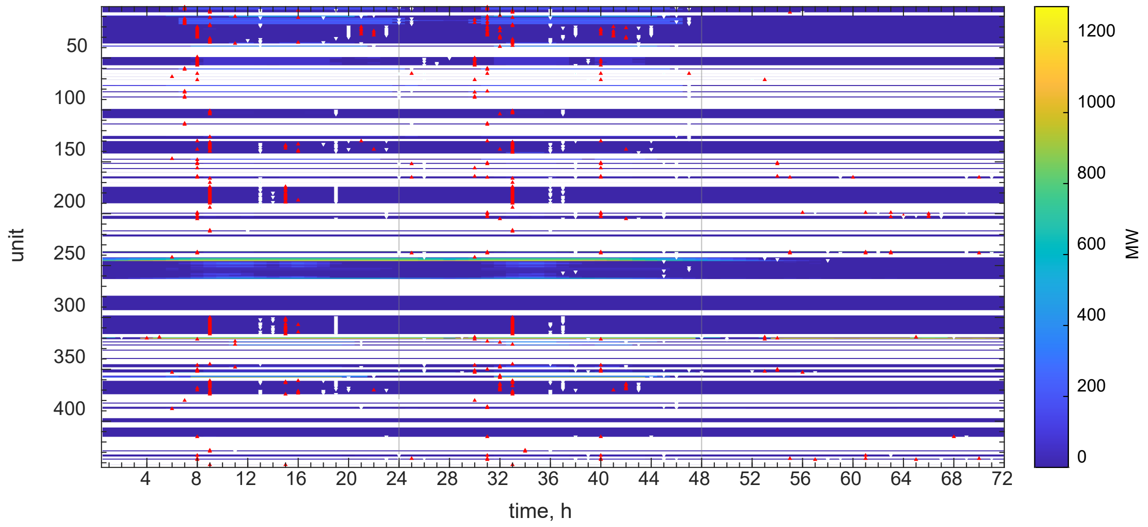
- Scheduling and dispatch:
  - Regulation*
  - Flexibility
  - Spinning (N-1 = 1298.7 MW)
- Risk
  - Flexibility: 10 MWh
  - Contingency: 130 MWh

```
VoLL  = 15,000 $/MWh
PRegu = 13,200 $/MW
Pflex = 13,100 $/MW
PSpin = 13,000 $/MW
```

444 total units
249 Active
149 Retired
Storage 3,844 MW, 1h


Power balance & headroom and footroom





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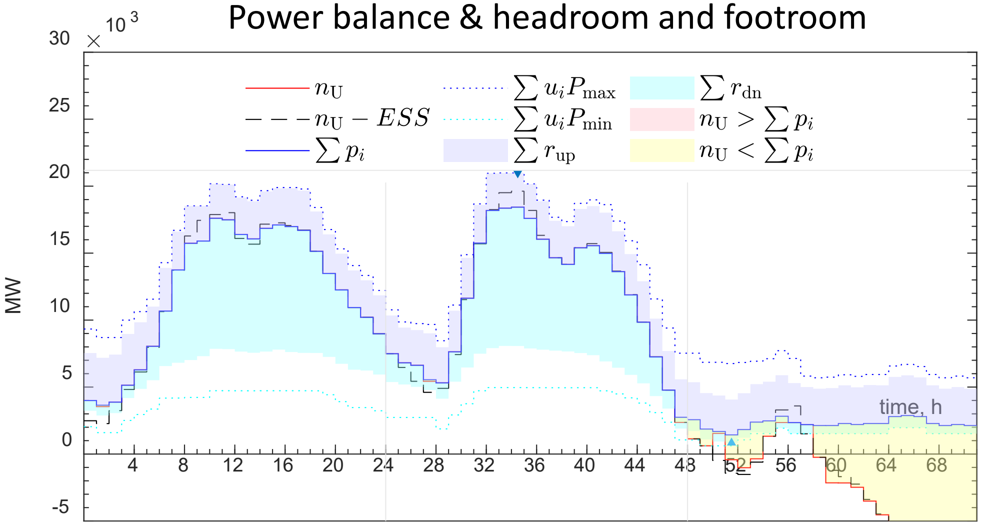
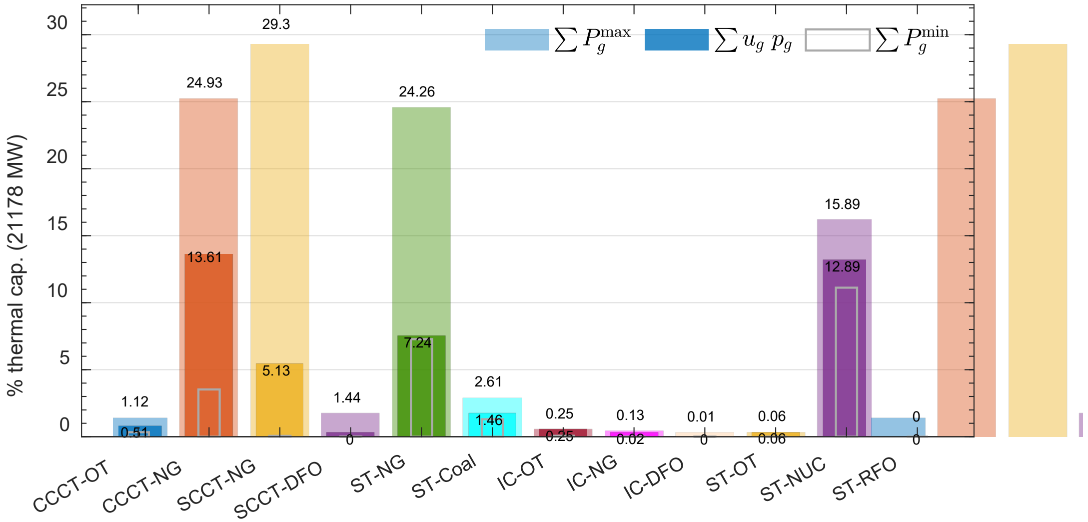
*https://www.nyiso.com/documents/20142/3694424/nyiso_regulation_req.pdf/6efc0df8-edc2-41bc-9e39-5fed576ba7bc

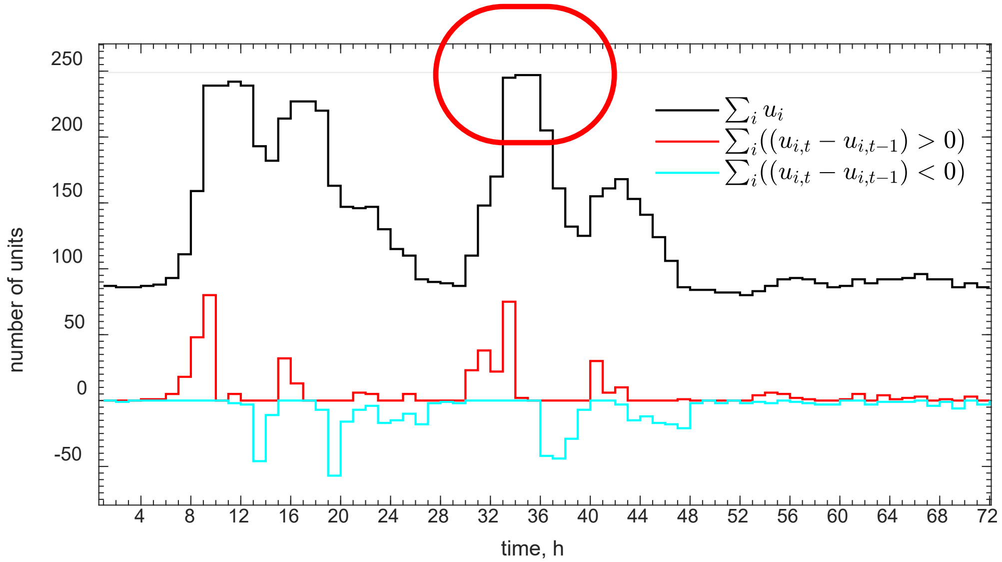
Capacity Utilization and Risk

```
OF              12,292,246.05_d
C_generation    10,809,256.67_d
C_no_load       1,371,404.30_d
C_SU            111,585.08_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       0.0000_d
C_SUPP_vi       0.0000_d
```

```
- Units used:   248    (99.59%)
- Commitments: 9427    (52.58%)
- Start-ups:    467
- Shut-downs:   466
```

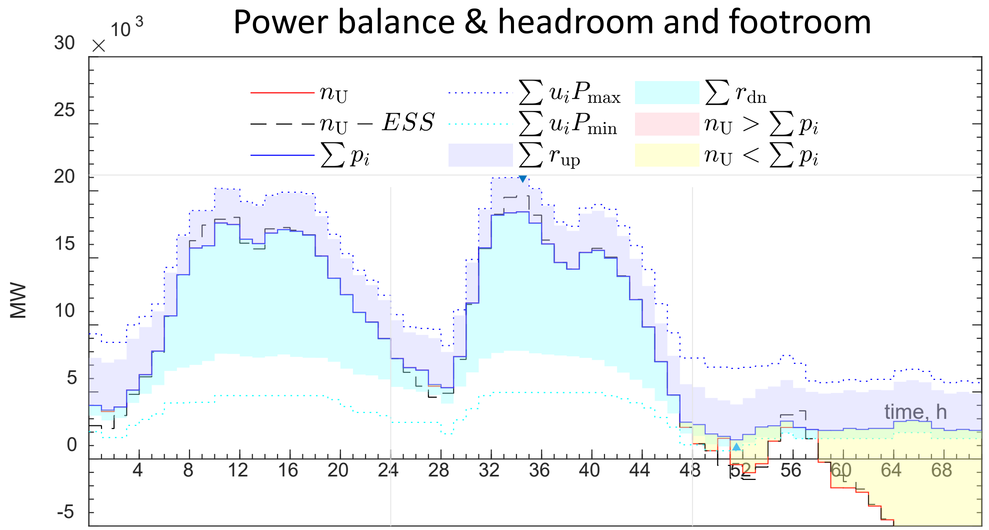


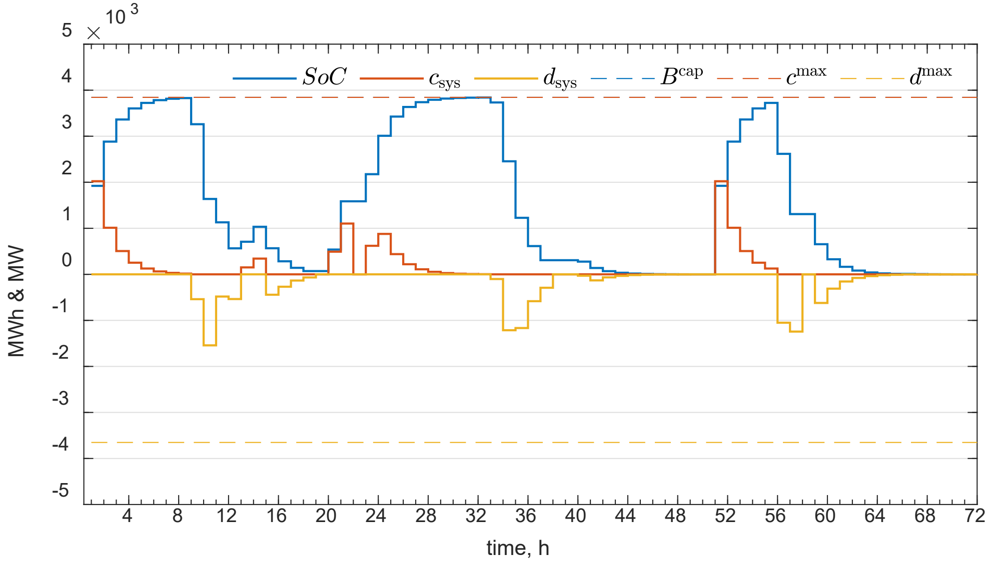


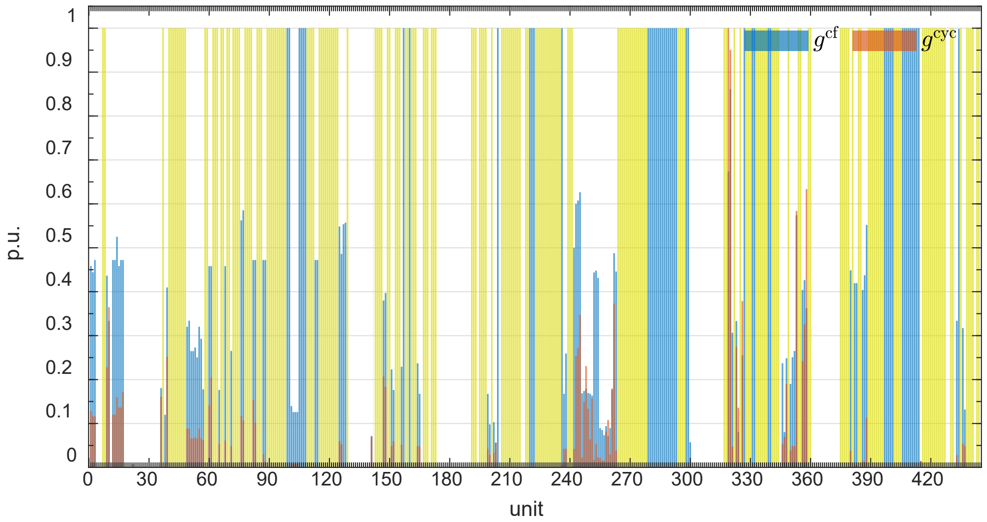


Risk Assessment

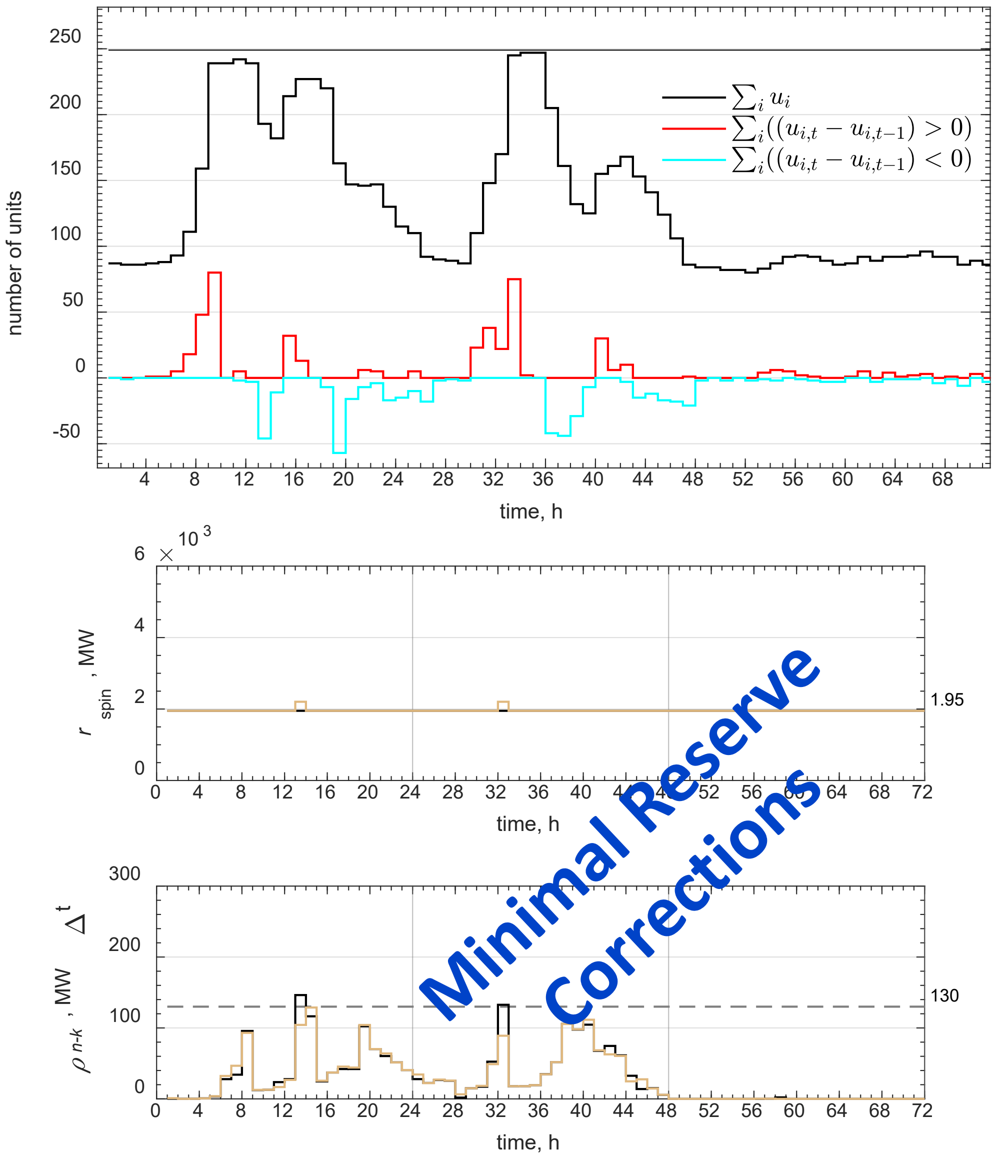
- Storage performs arbitrage
- By "shaving" load:
  - The number of thermal required reduces
  - The system can meet the reserve & risk requirements with existing resources
  - Storage is beneficial for economic efficiency and system security





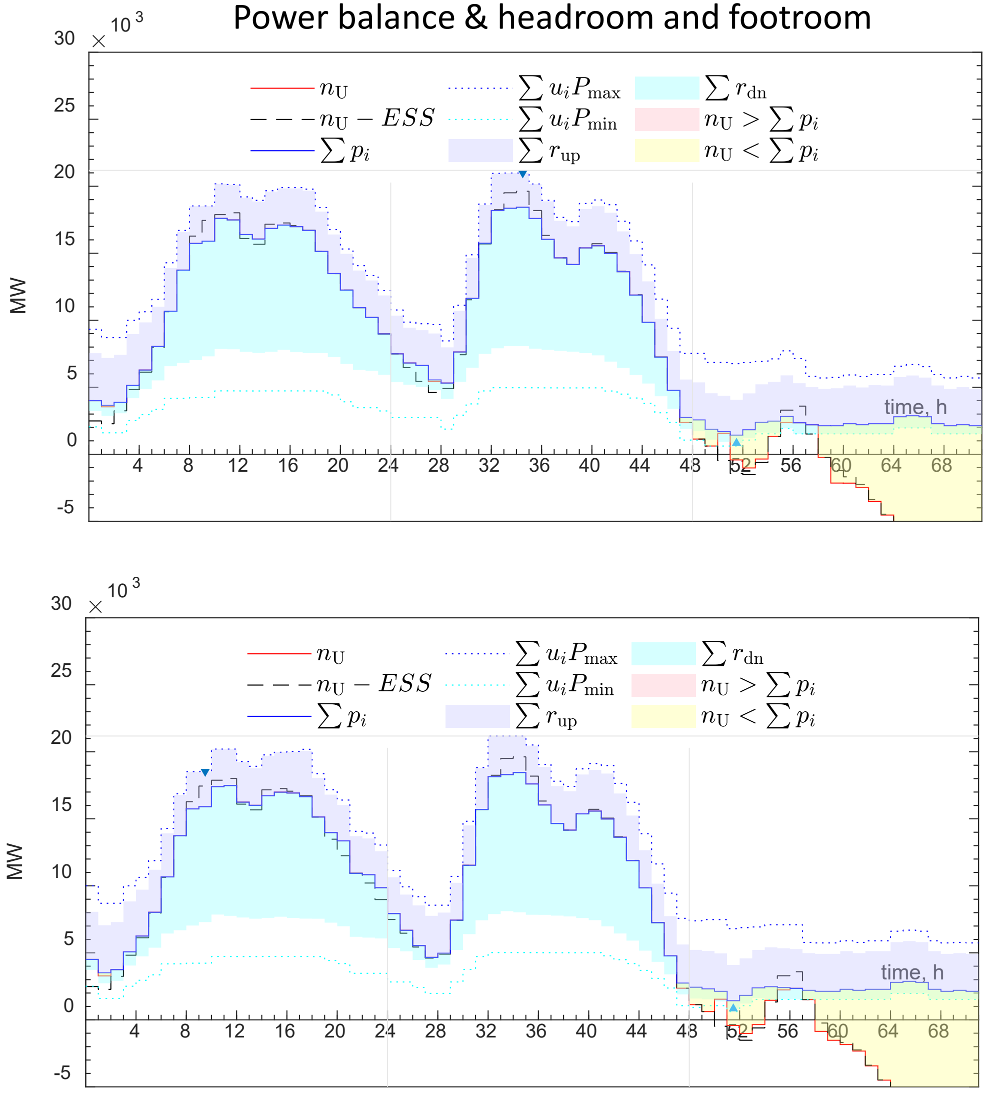


Reference with Storage no A/S: Risk Assessment



Minimal Reserve Corrections

Power balance & headroom and footroom



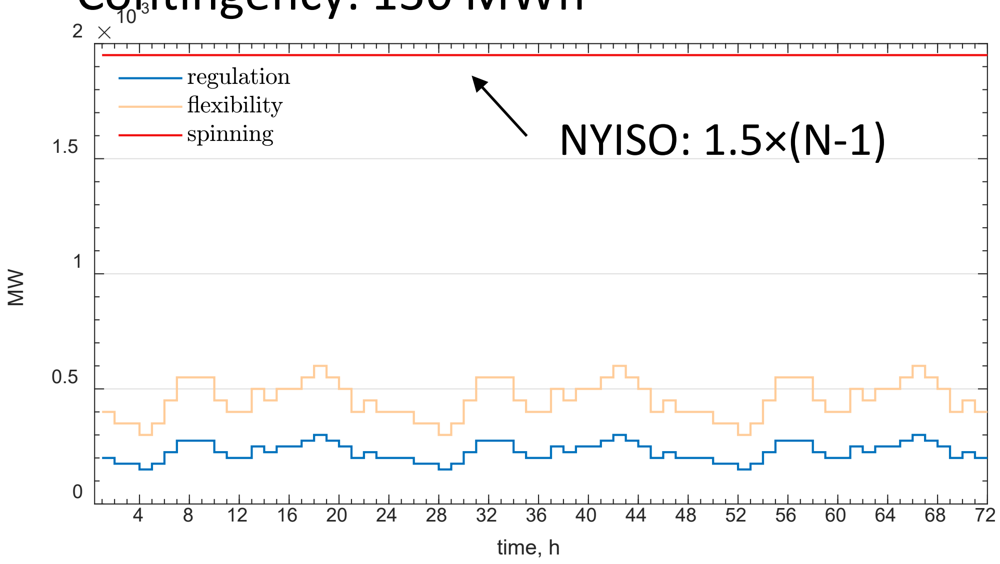
Reference Case, Storage with A/S (2035)

Scheduling and Dispatch

- Scheduling and dispatch:
  - Regulation*
  - Flexibility
  - Spinning (N-1 = 1298.7 MW)
- Risk
  - Flexibility: 10 MWh
  - Contingency: 130 MWh

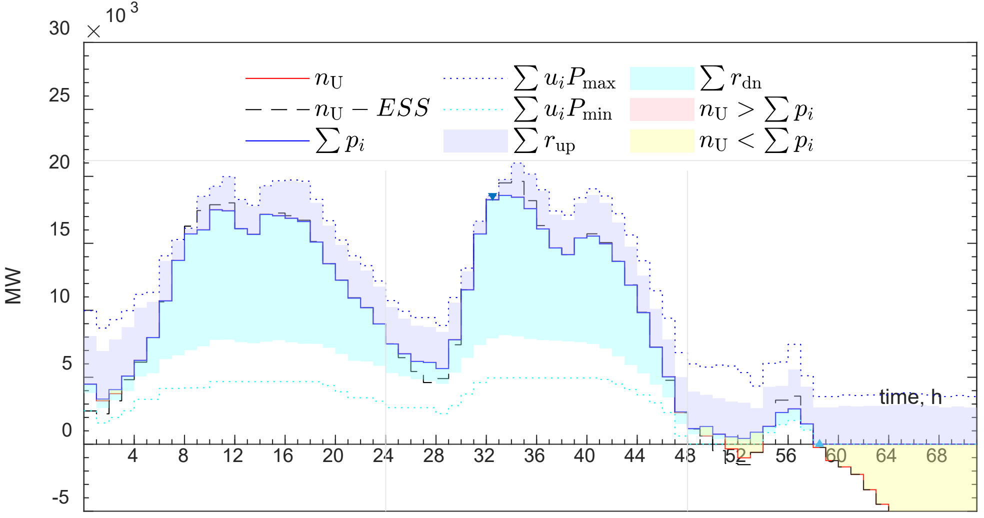
`VoLL  = 15,000 $/MWh`
`PRegu = 13,200 $/MW`
`Pflex = 13,100 $/MW`
`PSpin = 13,000 $/MW`

444 total units
249 Active
149 Retired
Storage 3,844 MW, 1h

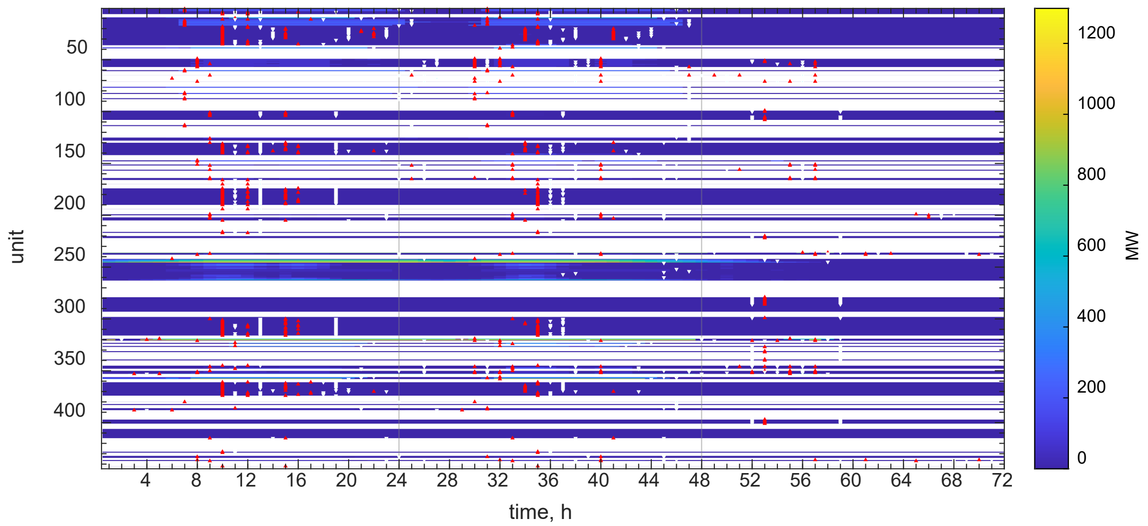


NYISO: 1.5×(N-1)

Power balance & headroom and footroom



Commitments, start-ups and shutdowns



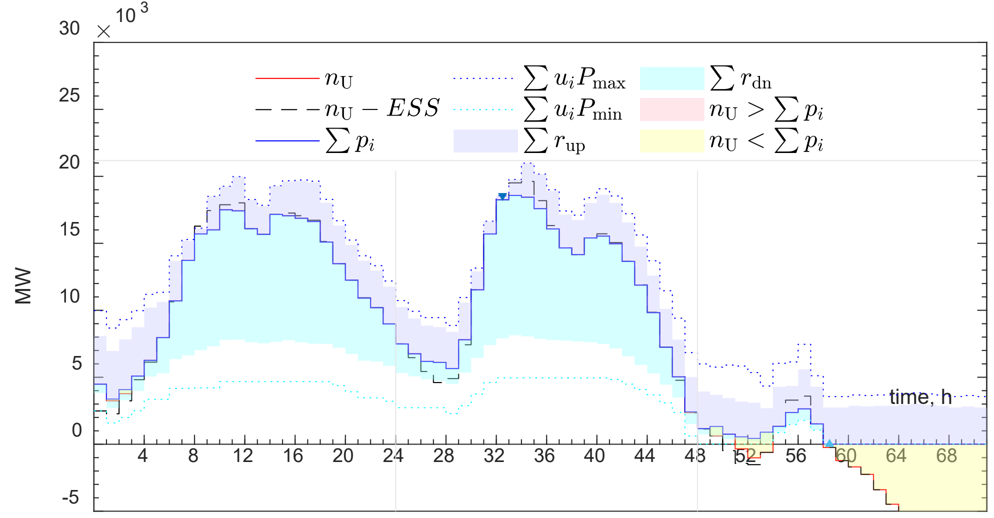
*https://www.nyiso.com/documents/20142/3694424/nyiso_regulation_req.pdf/6efc0df8-edc2-41bc-9e39-5fed576ba7bc

Capacity Utilization and Risk

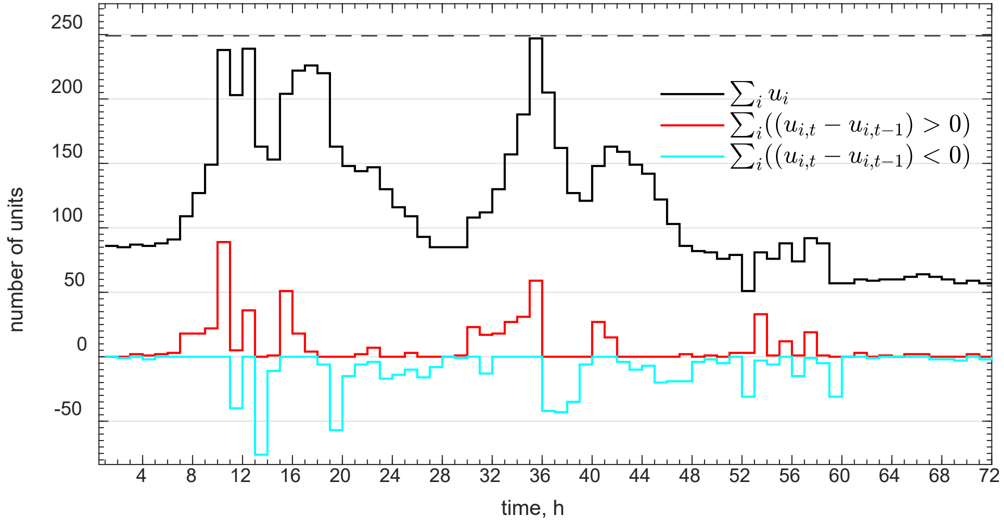
```
OF              12,074,001.57_d
C_generation    10,691,472.28_d
C_no_load       1,267,148.21_d
C_SU            111,585.08_d
C_ENS           0.0000_d
C_WIND_SPILLED  0.0000_d
C_PV_CURT       0.0000_d
C_RTPV_CURT     0.0000_d
C_REG_vi        0.0000_d
C_FLEX_vi       0.0000_d
C_SPIN_vi       3,796.00_d
```

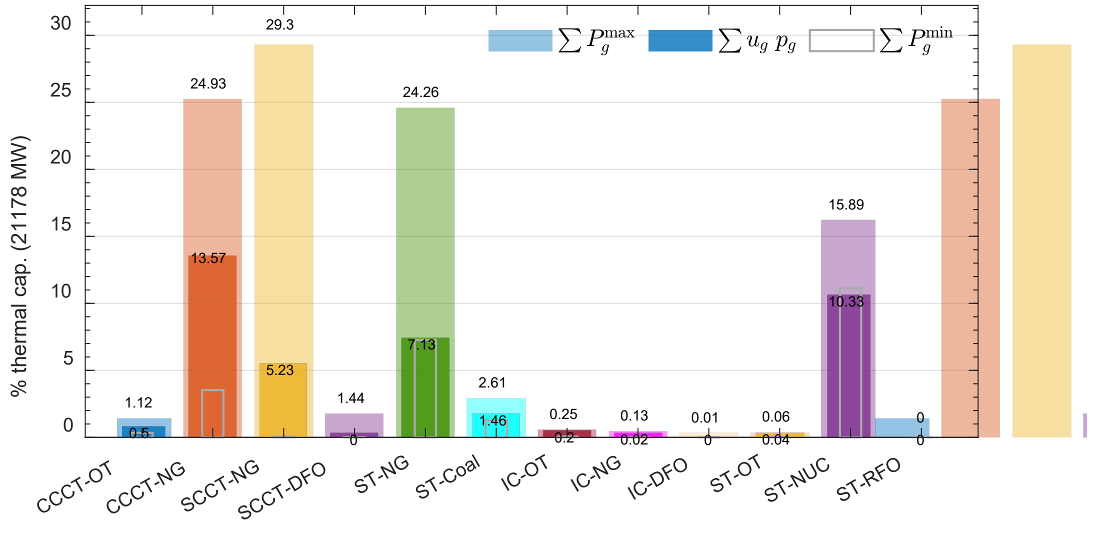
```
- Units used:   247    (99.20%)
- Commitments:  8409   (46.90%)
- Start-ups:    586
- Shut-downs:   615
```

Power balance & headroom and footroom



Commitments, start-ups and shutdowns

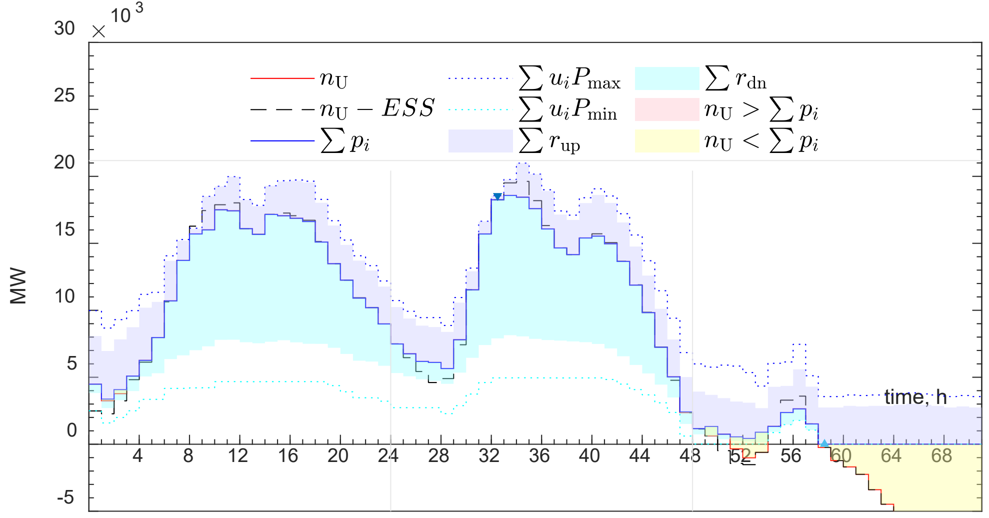


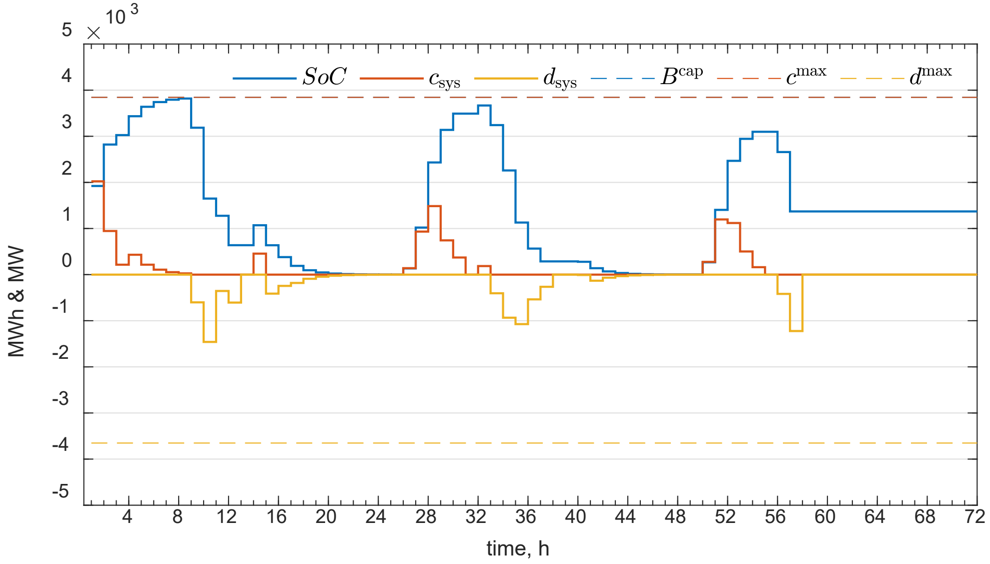


Risk Assessment

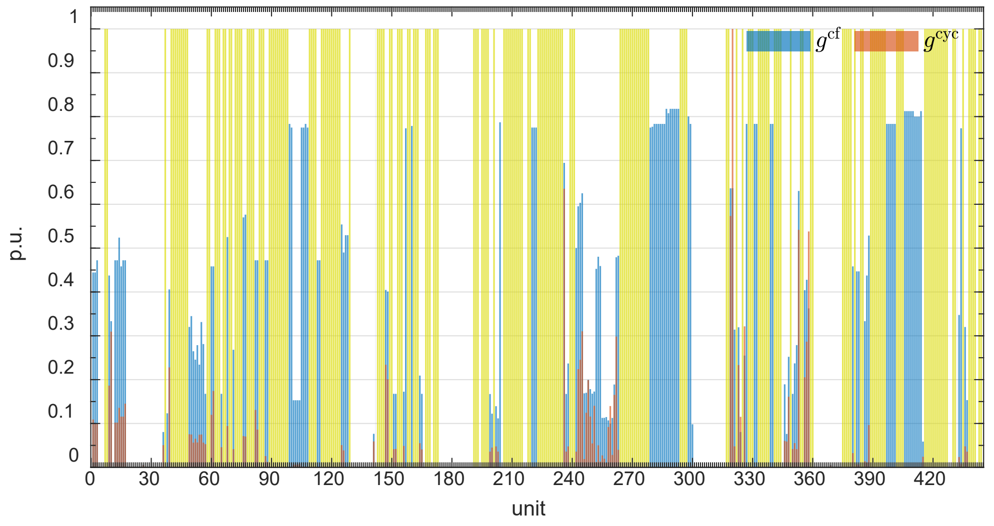
- Storage performs arbitrage and A/S
- Storage is fast and has large capacity
  - Can provide a large share of the A/S
  - Min(SoC, c^{max} - c)

Power balance & headroom and footroom

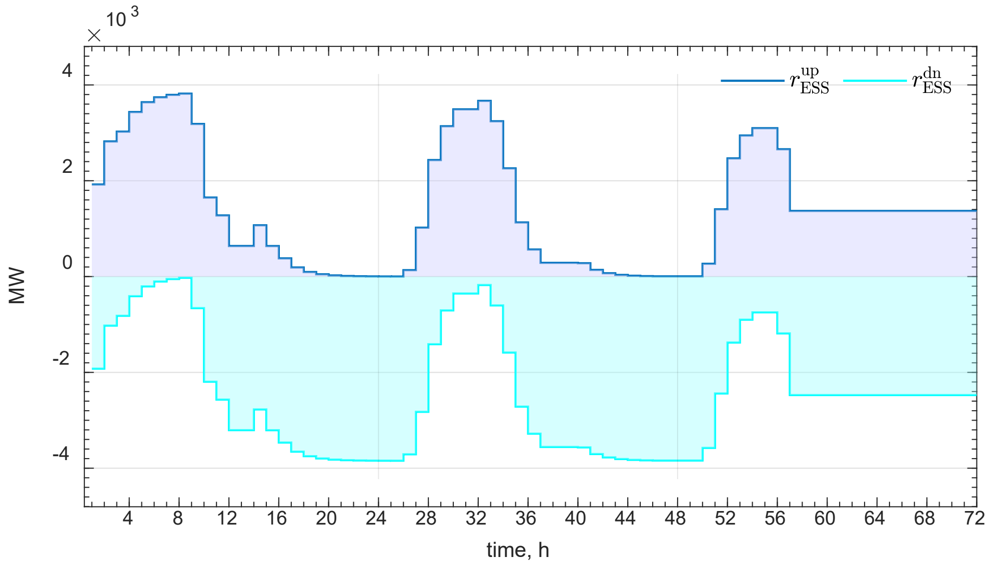


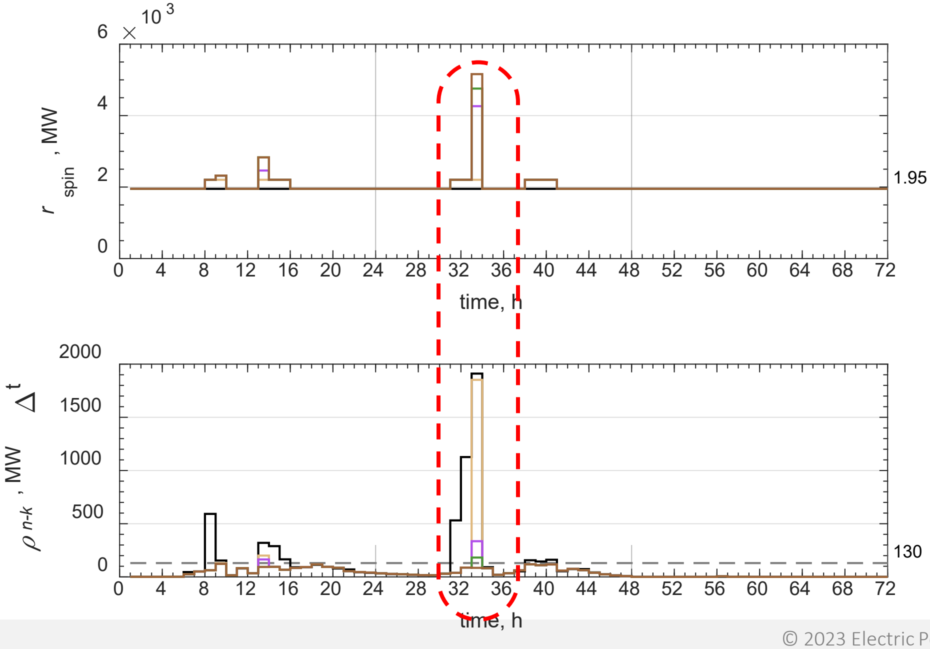


Generators capacity factor & cycling factor

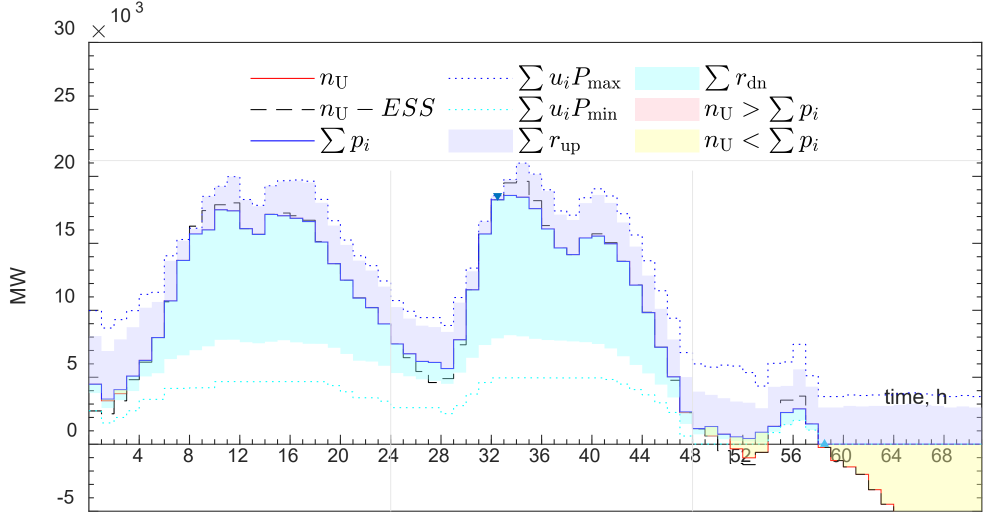


Risk Assessment

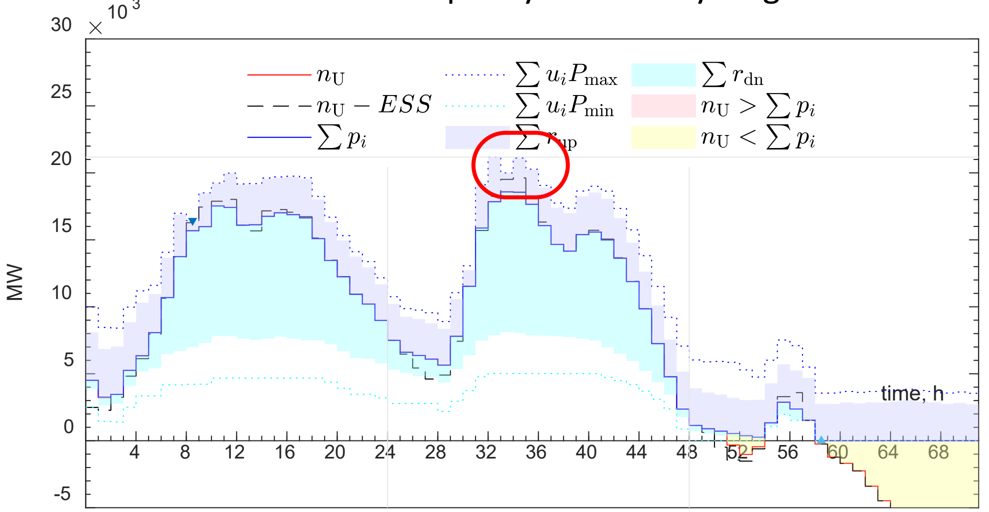




Power balance & headroom and footroom



Generators capacity factor & cycling factor



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- Results to fit your needs:
  - – Reports
  - – Guidelines
  - – Databases
  - – Software
  - – Training Modules
  - – Tools
  - – Videos
- Events, Webcasts, and Collaboration Spaces
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For questions or website assistance, please contact EPRI Customer Assistance Center (CAC) at askepri@epri.com or 800-313-3774, option 4.

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About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com